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The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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British contributions to science, 1851–1951

PART ONE

Science is international and of all time, and a review of British science in the last hundred years must therefore be in a double sense misrepresentative. If this is recognized, however, it may be not wholly insignificant. No one is so catholic as not to be specially influenced by the circumstances of his own time and place, and we may therefore expect some sort of unity, loose and obscure though it may be, in the contributions made by British workers to the general movement of science since the Great Exhibition in London in 1851. No attempt is made here to recognize and formulate that unity, but the more discerning reader may perhaps do so for himself.

In observational astronomy, the lead that Britain had established through the work of the Herschels and Lord Rosse had come to an end by the middle of the nineteenth century; it was soon to pass to America, where it still remains. This applies more particularly to telescopic observation. On the spectroscopic side, Huggins and Lockyer were pioneers in what has become the dominant part of astronomy, namely astrophysics. Huggins began the investigation of radial velocities of the heavenly bodies, which is still our chief source of information concerning the structure and mechanical behaviour of the universe. His elucidation of the nature of nebular matter, soon to be followed by Lockyer's similar interpretation of solar prominences, inaugurated the now conventional mode of attack on the problem of the chemical constitution of the universe. Furthermore, Lockyer's daring—and for long unaccepted—dissociation hypothesis, according to which atoms were broken up into simpler constituents in the hotter stars, paved the way for the yet more successful attack on the problem of the physical conditions obtaining throughout the universe, as well as for the atomic theories and discoveries which simultaneously revolutionized physics. When the character of Lockyer's dissociation idea was more clearly understood, the theoretical interpretation of his work, first by Saha and then by R. H. Fowler and Milne, led directly to our present knowledge of the structure of stellar atmospheres. As the further development of spectroscopic astronomy—its importance having thus become recognized—passed to regions better equipped for the purpose by nature and the munificence of man, Britain, through the work of Eddington, set afoot another of the major adventures of astronomy, namely the theoretical investigation of the conditions in the interiors of stars and in interstellar space.

At the time of the Great Exhibition the doctrine of energy was just becoming established in physics: one of the supreme generalizations of science. Its conservation—the subject of the first law of thermodynamics—was established largely through the work of Joule, and its degradation—the subject of the second law—largely through the work of William Thomson (Lord Kelvin). The application of these laws to an assumed molecular structure of matter owed as much to Clerk Maxwell as to anyone, and his investigations, with those of Boltzmann and, in a slightly different form, of Gibbs, remain the basis of the classical kinetic theory of gases. Maxwell and Larmor's contributions to electro-magnetic theory also remain the basis of modern ideas on that subject. They were essentially the mathematical expression of the earlier views of Faraday, and among their outstanding consequences, which Maxwell himself immediately realized, is the famous electro-magnetic theory of light, which united optics and electro-magnetism into a single subject. Maxwell was thus one of the founders of both the particle and the field concepts of physical theory, the interrelationships of which have since formed so puzzling a part of modern science. His concept of indestructible molecules, however, which was challenged by Lockyer's dissociation hypothesis, was profoundly modified at the end of the nineteenth century by J. J. Thomson's discovery of the electron.

The new situation, thus created almost simultaneously with the discovery in continental Europe of radioactivity and X-rays, was exploited to the full by Rutherford. By highly original methods, and inspired by highly original conceptions, he outlined the solar system model of the atom which led first, through his pupils Moseley and Bohr, to the understanding of the outer structure of atoms and the mechanism of radiation, and later, through his own work and that of an army of distinguished students, to what we now know of the atomic nucleus. In its early stages Bohr's theory of radiation was nourished and eventually brought to maturity largely through the experimental work of A. Fowler, a pupil of Lockyer's, and it may truly be said to be the valid form of the dissociation hypothesis. Nuclear work is at the moment the

chief centre of interest in physics, but what will come of it can be only conjectural.

Chemistry was ahead of physics in conceiving of the discrete structure of matter, and it was not until late in the nineteenth century that the true relations between Dalton's atoms and Maxwell's molecules were clearly seen. Thereafter, physical investigations amplified the chemist's periodic table in a manner unthought of by Newlands, who first pointed out the relation between the properties and the atomic weights of the elements, and by Mendelejeff, who, by his fuller treatment of it, secured general acceptance for the idea. It was thus fitting that the discovery of a whole new family of elements, which became known as the rare gases, should have been inaugurated by the joint work of a physicist, Lord Rayleigh, and a chemist, Sir William Ramsay. These gases—and especially helium, which was first discovered in the Sun by Lockyer and named by him as a new element twenty-seven years before being found on the Earth—have played an important part in clarifying the true relations between the elements. Early work on the disintegration of atoms gave Soddy the idea of isotopes, i.e. elements occupying the same place in the periodic table because of their identical chemical properties, but differing in atomic weight. Aston's perfected form of J. J. Thomson's early mass spectrograph was instrumental in revealing a large number of isotopes, and in transforming Prout's hypothesis—that the weights of all atoms are multiples of a single unit weight—from a speculation into an approximately correct form of an established fact. Space allows only the barest mention of the pioneer work of Sir William and Sir Lawrence Bragg in the determination of crystal structure by means of X-rays.

It is not inaccurate to say that in 1851 there was no general guiding conception in biology: the subject was approximately in the stage reached by astronomy when the first star maps were being constructed. The data were, of course, far more complex, and for their complete description were at least as dependent on the microscope as astronomy was on the telescope. The conception of evolution through natural selection, which we owe to Darwin and Russel Wallace and which came prominently before the scientific world and the general public through the publication of Darwin's *Origin of Species* in 1859, thus laid the foundation of generalized biology. Not only did it put forward the ancestry of individual species as a subject for scientific investigation, but it brought together previously independent lines of research in anthropology, ethnology, geology, palaeontology, physiology, anatomy, and other sciences, and showed them as contributing to an understanding of one grand process. The other great biological generalization—that concerned with the mechanism of heredity—as well as the discovery of the occurrence and importance of mutations, we owe to continental workers, though British contributions to its later development by Bateson and his school have been prominent. Mention of heredity inevitably brings to mind the original and indispensable work of Galton, who, though he reached no wide generalization in the subject and in fact did not aim at doing so, nevertheless facilitated advances of equal importance by the introduction and development of new techniques, particularly in the almost untouched field of the inheritance of mental characteristics. His most distinguished follower, Karl Pearson, not only carried his work further forward but contributed to the understanding of the fundamental meaning of scientific investigation.

As science advances, it becomes increasingly a matter of extending investigation into details, leading at irregular intervals to comprehensive co-ordinating conceptions. The latter stand out as the landmarks of progress, but the former are similarly indispensable and may demand abilities of different but scarcely lower quality. One cannot begin to mention the fundamental work on which later generations will build without realizing the arbitrariness of the choice that must inevitably be made. Nevertheless, in spite of his cherished presence still in our midst, it is impossible to omit a reference to Sir Charles Sherrington's outstanding work on the integrative action of the nervous system, which is unmistakably marked for endurance. Gowland Hopkins' discovery of the importance of the accessory food factors known as vitamins and Bayliss's discovery of hormones, are also events of great and permanent value. Work of this kind is unquestionably in the direct line of descent from that of the earlier seekers after truth for its own sake, but in biology particularly it is becoming more and more difficult to isolate basic contributions to science from their applications to the prevention and treatment of disease. Here again it is impossible justly to order events according to their importance. Lister's method of antiseptic surgery and Ross's discovery of the transmission of malaria by a particular species of mosquito are neither of them of prime importance in the progress of pure science, yet who can estimate their value as applications of science to the relief of man's estate?

The origin of the solar system

SIR HAROLD SPENCER JONES

The problem of the origin of the solar system is the most difficult in cosmogony and has been an intellectual challenge for some two and a half centuries. The very plausible theories put forward by such eminent men as Kant, Laplace, Fouché, Jeans and Jeffreys, Lyttleton, Hoyle, and Alfvén, have all in time had serious doubts cast upon them. At present there is great interest in Weizsäcker's theory, which is in some respects related to that put forward by Kant in 1755 and regards the solar system as resulting by evolution from a primordium rather than by the cataclysmic intervention of some other celestial body.

The solar system shows so many regularities, both in its dynamical and in its physical properties, that it cannot have been formed by chance. This fact was emphasized first by Laplace, who, in the *Exposition du Système du Monde* (1796), pointed out that the planets move round the Sun in the same direction and nearly in the same plane; that the satellites move round their parent planets in this same direction and nearly in the same plane as the planets; that the Sun, the planets, and their satellites rotate in the same sense as that of their revolution; and that the inclinations of their equators to their orbits are small. Laplace estimated that the odds against these regularities being due to chance was more than two hundred thousand milliards (2×10^{14}) to one.

Since the time of Laplace the known solar system has been enlarged by the discovery of two planets, of fifteen satellites, and of more than 1500 asteroids. With a few exceptions, these additional members show the same regularities. A further significant feature of the solar system, which was not mentioned by Laplace, is that the eccentricities of the orbits of the planets and of their satellites are, with few exceptions, small. No theory of the origin of the solar system can be considered as satisfactory unless it is able to account for these features of the system.

There are other characteristics of the system which must be mentioned. The planets can be divided into two groups having important differences. The inner planets have relatively small masses, high densities, slow rotations, and few satellites. The outer planets have large masses, low densities, rapid rotations, and many satellites. Pluto, the outermost known planet, is anomalous in many respects.

A curious empirical law connecting the mean distances of the planets from the Sun was formulated by Bode in 1772. Bode's law can be expressed in the form:

$$r_n = a + b \cdot 2^n,$$

in which r_n denotes the distance of the nth planet from the Sun, and a and b are constants. It requires a planet between Mars and Jupiter which, at the time it was formulated, was missing; the subsequent discovery of the asteroids, which are possibly the remnants of a disrupted planet, can be regarded as having filled the gap. Uranus, Neptune, and Pluto were not discovered until after 1772. Though Adams and Leverrier both used Bode's law in predicting the position of the unknown planet assumed to be responsible for the perturbations of Uranus, Neptune does not fit the law very well, and Pluto does not fit it at all. A better fit for the outer planets can be obtained, however, by an adjustment of the constants of the formula. The relative distances from their parent planet of the satellites of Jupiter, Saturn, and Uranus can be fitted fairly well to a similar law. This type of distance-law may therefore be of significance for the mode of formation of the solar system.

The distribution of angular momentum in the solar system is peculiar. The Sun, which has more than 99 per cent. of the mass of the system, contributes through its rotation a mere two per cent. to the total angular momentum; the major planets, on the other hand, though they contain less than one-seventh of one per cent. of the total mass, contribute in their orbital motions almost the whole (98 per cent.) of the angular momentum of the system. The rotations of the planets and the motions of their satellites contribute a negligible amount. The satellite systems of the major planets show quite a different distribution of angular momentum, the rotation of the central body

contributing much the greater part. In the solar system the puzzle is not why the planets have so much angular momentum, but why the Sun has so little.

Very many different theories have been proposed, for it has proved to be the most difficult problem in cosmogony. The various theories can be divided into two groups, the monistic and the dualistic. The monistic theories suppose that the system was formed by a process of evolution from a primordial system, without interaction from any outside forces; the dualistic theories suppose that it was formed through the intervention of some other celestial body, usually involving a cataclysmic action.

The earliest theory worthy of mention was proposed in 1755 by Immanuel Kant in his *Allgemeine Naturgeschichte und Theorie des Himmels*. He supposed that the Sun was originally at the centre of a nebula that was in rotation round the Sun under its gravitational attraction. Collisions between the separate particles caused the nebula to flatten out into a disk. The matter in this disk gradually collected round the denser portions, forming a number of smaller systems, each in rotation. Kant supposed that in each of these sub-systems a similar evolution took place, either a planet or a planet and satellite system being formed. The larger the sub-system, the greater its gravitational attraction and the larger the number of satellites. The theory gave a plausible explanation of the common orbital plane and of the common direction of rotation and revolution, but it is unable to account for the distribution of angular momentum. Kant was, of course, unaware of this difficulty. The theory is of interest because, as we shall see, it has been revived with modifications in recent years.

Laplace, who did not know of Kant's theory, proposed a somewhat different theory in his *Exposition du Système du Monde*. He supposed that the Sun was originally surrounded by a hot gaseous atmosphere, which gradually cooled, contracting at the same time. The rate of rotation increased as the contraction progressed, until eventually the centrifugal force at the equator became greater than the gravitational force, when a ring of matter was thrown off. The process was repeated, a succession of rings being formed. The central mass eventually became our present Sun. Each ring was supposed to condense into a smaller nebula, in which the process was repeated, giving rise to the planet and satellite systems.

Laplace's theory is untenable for several reasons. Clerk Maxwell in 1859 showed that a ring, such as would have been thrown off by the contracting mass, would not coalesce to form a single body, but that its final stable state would consist of a large number of small bodies; a swarm of asteroids might, in fact, be produced in such a way, but not a planet. The theory breaks down also over the angular momentum difficulty. If the whole of the angular momentum of the solar system were concentrated in the Sun, its period of rotation, instead of being 27 days as at present, would be about 12 hours; the centrifugal force at its equator would even then be only 5 per cent. of the force of gravity, so that rings of matter could not have been thrown off in the way Laplace had supposed.

The angular momentum difficulty was first emphasized by Fouché in 1884. It is inherent in any monistic theory. It was natural, therefore, to inquire whether a workable theory could be constructed on the assumption that the angular momentum of the system had at some time in the past been changed by the intervention of an outside body. Chamberlin and Moulton in 1910 suggested that another star in its passage through space had chanced to pass close to the Sun. The two bodies, mutually attracted by their gravitational pull, swung round one another in hyperbolic orbits, their closest approach being a few solar diameters, and then separated. The tidal action of the passing star raised an enormous wave on the Sun, which, aided by the expansion of the hot compressed solar gases, produced a succession of huge eruptions. The ejected material was dragged round by the gravitational pull of the passing star, so that it was caused to move in eccentric orbits round the Sun and more or less in the same plane. Chamberlin and Moulton supposed that this matter would condense into liquid droplets or planetesimals, which would quickly solidify, and that the larger particles would grow, at first by other particles sticking to them when they collided, and then by accretion due to gravitational attraction. The residual matter would form a resisting medium, which would gradually reduce the eccentricities of the orbits to small values. Some of the matter would escape from the system; some would fall back on the Sun and give it a rotation in the same direction as the orbital motion. The planets are supposed similarly to have been set in rotation by matter, which had acquired momentum from the star, falling back upon them. The satellites are assumed to have grown from smaller nuclei close to the large planetary nuclei.

The objection was raised by Jeffreys that the collisions between the planetesimals would be so

frequent, and would occur with such high velocities, that they would be volatilized into a mixture of gas and fine dust long before accretion could have any appreciable effect. A modified form of the planetesimal theory was consequently proposed by Jeans and Jeffreys. They supposed that the passing star, when near its closest approach, raised a large tidal protuberance on the Sun, from the pointed end of which a stream of matter, in the form of an elongated cigar-shaped filament, was drawn out. Such a filament is longitudinally unstable, and would consequently break up under its own gravitation into a string of separate masses or protoplanets, the smallest at the two ends and the largest in the middle range of distance. Each of these separate masses would move in an elliptical orbit round the Sun. The satellites are supposed to have originated by tidal disruption of the protoplanets by the Sun's attraction at the first perihelion passage after their formation. The small eccentricities of the planetary orbits, and the rotations of the Sun and planets, are explained as in the planetesimal theory.

Plausible as this theory appears at first sight, it is not without serious difficulties. The tidal forces acting on the filament would set it in bodily motion, but could impart little rotation, if any. Jeffreys calculated that, to account for Jupiter's rotation, the amount of matter that would have had to fall back on to it and to be reabsorbed by it would be about 400 times greater than that of all its satellites, which does not seem possible. In the second place, Nölke has queried whether the resisting medium could possibly have brought about the small orbital eccentricities; the majority of the collisions between the particles of the medium and a planet would be inelastic, and consequently a large reduction in the eccentricity could be achieved only by a very great increase in mass through accretion, which is improbable. Further, the material drawn out from the Sun would be at a temperature of a million degrees or more, and under high pressure (exceeding a million atmospheres). Spitzer in 1939 pointed out that it would tend to dissipate rapidly into space; at a temperature of a million degrees hydrogen atoms, for instance, have a mean velocity of about a hundred miles a second. It does not seem possible that condensation could have taken place before the matter had dissipated.

To avoid the difficulty of the rotation of the planets, Jeffreys modified the theory by assuming that, instead of a close approach of the star and the Sun, an actual collision had occurred, somewhat like a 'half-ball' impact. The two bodies would approach each other with enormous speeds and, as they drew near each other, great tides would be raised on them; matter would begin to be ejected from the tidal protuberances before the actual collision occurred. During the collision, the heavy cores of the two bodies would swing round each other in a sharp curve and, separating, move off into space. The nearer portions of the Sun and star would intermingle, and become greatly compressed and heated to a temperature of several million degrees. The shearing motion would cause rapid rotation; as the two bodies separated, a filament of hot gaseous matter, having a rapid whirling motion, would be drawn out between them. The subsequent course of events would be much as in the case of a near approach. Spitzer's objection applies also to this form of the theory.

Jeans had supposed, in order to account for the distribution of angular momentum, that at the time of the formation of the planets the Sun was much more distended than it now is, so that the matter which condensed into the outer planets did not have to be drawn out to a great distance. However, much has since been learnt about stellar evolution, and it is certain that when the solar system was born, a few thousand million years ago, the Sun was almost in its present state. The matter from which Jupiter was formed had, therefore, to be drawn out to a distance about one hundred times greater than the distance of nearest approach between the Sun and the star, while the matter from which Neptune was formed had to be drawn out to about 500 times this distance. The matter would be moving almost radially outwards from the Sun at such distances, and would therefore have but little angular momentum. Russell has shown that, under the most favourable suppositions possible, the angular momentum per ton of the matter drawn out would be less than one-tenth of the average angular momentum per ton of the planetary system.

The conclusion is that no collision theory that supposes the planets to have been formed from matter drawn out from the Sun can be made to work. Russell therefore suggested that the Sun might originally have been a binary star, having a small companion revolving round it at a distance comparable with the distances of the present major planets, and that the intruding star collided not with the Sun itself but with its companion. The angular momentum difficulty could then be avoided, for the angular momentum would be already present in the orbital revolution of the

companion. This suggestion was investigated by Lyttleton, who succeeded in showing that, under certain conditions, it would be possible for both the Sun's companion and the colliding star to escape from the neighbourhood of the Sun, while at the same time leaving under the Sun's gravitational control sufficient of the matter torn off by the collision to form the planets. Spitzer's objection that the ejected matter would not condense into planets applies in this case also, while the differences between the inner and the outer planets remain unexplained.

To meet the difficulty about condensation, Lyttleton suggested that the planets might have been formed by a two-stage process. If the star was broken up by the collision into fragments, there might have been one or more portions of a sufficient size to be held together by gravitational attraction. As such a fragment cools and contracts, its rate of rotation might increase beyond the limit of stability, when it would break up into two separate bodies; secondary disturbances might have caused smaller fragments to break off, which might have continued with the main bodies to form their satellites. Other fragments might have formed the inner planets and the Moon. At least two separate main bodies would be needed to account for the major planets. A strong objection to this theory is that the rate of rotation required for instability and fission to occur is appreciably faster than the rotation of any of the planets.

Working on the idea that fission may have played an important part in the formation of the system, Lyttleton has put forward another theory. He assumes that the Sun was initially a triple star, having two smaller companions in close proximity. Basing his argument on the view that the evolution of a close binary system is associated with the accretion of interstellar matter by gravitational attraction, the slow increase in the masses of the two components would cause their separation gradually to decrease and eventually bring about their coalescence. The angular momentum of the combined body might be too great for stability; the system would then split up into two bodies which, under suitable circumstances, might both escape from the system, leaving merely a wisp of matter, part of the debris of the cataclysm, from which he supposes that the planets could have been formed. This theory is open to the same objections as the other theories which assume that the planets were formed from matter ejected from a star, and it does not appear capable of accounting for many of the regularities of the solar system.

A catastrophic theory of a different type has been proposed by Hoyle, who supposes that the Sun was once a member of a binary system with a very massive companion, which developed into what is termed a supernova. Such a star passes through a stage of instability in which its brightness increases in a few days by 15 or 20 stellar magnitudes, emitting during its brief eruption as much energy as the Sun emits in the course of a million years. Matter is ejected at a temperature of many millions of degrees, and with speeds up to several thousand kilometres a second, the total amount being perhaps several times the mass of the Sun. Hoyle suggests that an asymmetry of only a few per cent. in this ejection would be sufficient to give the star a recoil that would break its gravitational connection with the Sun, the separation before the outburst being assumed to be comparable with the distance between the Sun and Jupiter.

The material ejected in the initial stages of the eruption would be moving far too fast to be captured by the Sun, but when the eruption was in its final stages the speed of ejection would rapidly diminish, and it is conceivable that a wisp of matter might be captured by the Sun and condense to form planets. There is no difficulty about the angular momentum of the planets, as it is already present in the system, while the direct rotation of the planets is explained as in other catastrophic theories. The objection that matter ejected at an extremely high temperature would be dissipated before it could be captured by the Sun and condense applies with still greater force to this theory. The basic idea underlying it appears to be that the Earth and, according to Hoyle, also the other planets contain relatively small amounts of hydrogen and helium, which are the two elements with the greatest cosmical abundance. Hoyle believes a supernova to be a star with such a high internal temperature that it has used up almost all its hydrogen in the formation of heavier elements. There are, however, strong reasons for believing that the terrestrial planets lost most of their hydrogen and helium in their early history, while the low mean densities of the major planets prove that their very extensive atmospheres still contain a great amount of these light gases.

The failure of the many attempts to form a satisfactory dualistic theory has caused renewed attempts to be made in recent years to develop a monistic theory, not requiring the intervention of any other star or the assumption that the Sun was a component of a double or triple system.

It has been established in recent years that there are in the galactic regions numerous interstellar clouds of gas and of small particles, called smoke for convenience. Whipple supposes that the Sun and planets were formed in such a cloud of gas and smoke, which is assumed to have had a radius of about 30,000 astronomical units and a total mass not much greater than that of the Sun. The cloud contracted under its gravitational attraction, while the Sun was condensing out of the largest aggregation in the cloud. Differential motions have been observed in some of the clouds; Whipple assumes that the planets were formed from condensations in a stream in this cloud. The angular momentum difficulty is thus side-tracked by assuming that the necessary amount was present in the beginning. The condensations, in moving through the cloud, would grow by accretion of matter with zero angular momentum; they would therefore spiral inwards towards the Sun. Whipple gives a qualitative explanation of the planetary rotations, but other regularities in the solar system are not explained, and the theory requires much further development before it can be decided whether it is capable of providing a plausible explanation of the origin of the solar system.

A theory of considerable interest has been developed by Alfvén, which introduces a new consideration. It is based upon the existence of a general magnetic field of the Sun, and on the supposition that electromagnetic forces were predominant in the formation of the planetary system. Assuming the Sun to have a general magnetic field of intensity about 50 gauss, Alfvén remarks that the electromagnetic force on a proton moving along the Earth's orbit would be some 60,000 times greater than the gravitational force arising from the Sun's gravitational attraction.

Alfvén supposes that the Sun in its motion through space entered one of the interstellar gas clouds, consisting of neutral atoms. Under the influence of the Sun's gravitation, the atoms would fall in towards the Sun with accelerated velocities, so that in the vicinity of the Sun the cloud would be heated up. Alfvén assumes that, when the kinetic energy of the atoms becomes equal to the energy of ionization, the atoms would become ionized by collisions. The resulting mixture of positively charged ions and negatively charged electrons would then be subjected to electromagnetic forces from the Sun's magnetic field. Electric currents would be induced in the ionized cloud by the rotating magnetic field of the Sun, and an effect similar to that of the damping of a metal plate rotating between the poles of a magnet would take place. The cloud would be accelerated in the direction of its rotation at the expense of the retardation of the Sun. Angular momentum would, in fact, be transferred from the Sun to the cloud. The angular momentum difficulty can therefore be avoided, if it is supposed that the Sun initially rotated more rapidly than it does at present. With reasonable assumptions, Alfvén calculated that in 100,000 years about 10 per cent. of the Sun's angular momentum would be transferred to the cloud. He finds that the braking effect on the Sun would be greater the higher the heliographic latitude; it is a well-established fact that the Sun rotates less rapidly near its poles than near its equator.

Once an ion has been formed, it will move outwards spirally along the magnetic lines of force and will reach an equilibrium position in the equatorial plane, when it will revolve round the Sun. Assuming that the ions are all ionized at the same distance from the Sun, Alfvén is able to calculate the distribution of mass in the equatorial disk, and finds that it agrees roughly with the actual mass distribution in the range of distance occupied by the major planets. He supposes that the ions and electrons recombine when in their equilibrium position, and that condensation then takes place, planetesimals being formed first and then planets. The outer planets are thus accounted for.

As the distance from the Sun at which ionization would take place is much greater than the distance of Mercury, it is not possible to account for Mercury by this process; the other inner planets, if formed in this way, would have densities less than those of the outer planets. The theory could account for Venus, for example, only if it consisted entirely of hydrogen. A somewhat different mechanism is accordingly proposed to account for the inner planets. It is assumed, quite reasonably, that the cloud contained smoke particles as well as atoms. These particles would fall towards the Sun and would come well within the distance at which the atoms are ionized before being vaporized. When this happens, ionization of the resulting gas occurs and the charged particles are then repelled along the innermost lines of force and finally condense to form the terrestrial planets. Alfvén assumes that the planets would be magnetized, and that the same process would be repeated on a small scale to form satellites.

This theory appears at first sight to be able to account for many points of detail in the structure of the solar system, and to provide rough quantitative

estimates of the distribution of mass between the planets, in fairly good agreement with the actual distribution. It is based fundamentally on the existence of a general magnetic field of the Sun. From observations made about thirty years ago at Mount Wilson it was concluded, as mentioned above, that the Sun has a field of intensity 50 gauss, though there remained some doubts about the validity of the result. Recent observers at Hamburg, Mount Wilson, and Cambridge agree that the intensity of the field is now not greater than the probable error of its determination—about 2 gauss. The field may possibly be variable, but the whole basis of Alfvén's theory is rendered doubtful.

There are other objections; ter Haar has shown that ionization by collision will not occur in the gaseous cloud surrounding the Sun, as postulated by Alfvén, and that ionization by solar radiation will not occur at the distances of the outer planets and almost certainly not in the region of the inner planets. It is doubtful, moreover, whether condensation into planets would occur, even if the equatorial disk were formed in the way supposed by Alfvén.

A theory of great promise, which has attracted much interest, has recently been proposed by Weizsäcker. It is a modification of Kant's theory, and assumes that the primitive Sun was surrounded by a rotating shell, consisting of an aggregation of atoms and smoke particles, of total mass about one-tenth the mass of the central Sun, in which each particle moved round the Sun in an independent orbit. The composition of the cloud is supposed to have been the same as that of the Sun, consisting therefore of about 99 per cent. of hydrogen and helium and about 1 per cent. of heavier elements.

Internal frictions within the cloud will change the shape and orientation of the orbits of the various particles until they are eventually reduced to orbits of nearly circular shape in the neighbourhood of the Sun's equatorial plane; the envelope would then be in the form of a disk whose diameter is comparable with the present diameter of the solar system, and whose thickness is less than one-hundredth of the diameter. The disk consists mainly of gas, interspersed with a much smaller quantity of smoke particles, each particle moving practically in an independent gravitational orbit. It would be in temperature equilibrium, there being a balance at any point between the energy received from the Sun and the energy radiated, so that the temperatures would not be greatly different from the present planetary temperatures.

Viscous forces would tend to equalize the angular velocities, slowing down the faster-moving inner parts and speeding up the slower-moving outer parts of the disk. The inner parts, as they slowed down, would fall nearer the Sun, while the outer parts, as they were speeded up, would move further away. This process brings about a gradual transfer of angular momentum from the inner parts of the system to the outer. There would be a gradual dispersion into interstellar space of the hydrogen and helium in the outer portions of the envelope, carrying away the troublesome angular momentum that would have had to be accounted for if the material had fallen into the Sun. It is the mass with low angular momentum that falls into the Sun. Weizsäcker computes that the original density of the envelope would be reduced to the present density of interplanetary space in about 200 million years, which explains why the envelope is not in existence today.

Weizsäcker then considers how quasi-steady states, requiring but little energy for their maintenance, could be formed in the material round the Sun. A group of particles having orbits with the same period of revolution and semi-major axes, but with different eccentricities, will appear, when viewed from axes rotating with the common period, to be describing about the moving origin small ellipses which have a common ratio (2 : 1) of major axis to minor axis, the minor axis pointing to the Sun. They will therefore form a sort of vortex in the rotating system, in which the circulation is in an opposite sense to that of the rotation of the gaseous disk. The vortex can capture other particles only if their angular momentum lies below a certain threshold value, so that there must be an upper limit to its size. If the maximum eccentricity is 1/3, Weizsäcker shows that five such vortices can be fitted into an annulus round the Sun. A stable arrangement is provided by a series of such annuli, each revolving round the Sun, the ratio of the radii of two consecutive annuli then being found to be constant. The radii of the rings consequently follow a law which is a close approximation to Bode's law.

With such a distribution of vortices, there are steep velocity gradients in the neighbourhood of the circles between successive rings of vortices. Large viscous stresses will be set up, and secondary eddies, which may be regarded as in the nature of roller bearings, will form around the rings. The circulation in these eddies will be opposite to that in the vortices and therefore the same as the direction of the disk. It is found that the conditions for

condensation would be more favourable in the roller bearings than in the vortices. The process of condensation has been studied in some detail by ter Haar. Condensation can occur only if the vapour pressure of large particles is less than the pressure in the gas, so that more atoms will condense on the particles than will evaporate from them. The nature of the condensation particles is determined mainly by the temperature; it is found that in the outer regions compounds like water, ammonia, and carbon dioxide can condense, but that in the inner regions only the metals and inorganic compounds which are heavier and less abundant can condense. Thus in the first stage of the condensation, the nuclei which form on the inner rings have higher densities than those which form on the outer rings. The second stage consists in growth by accretion of impinging particles sticking to the nuclei, which will occur more rapidly in the outer rings than in the inner. The final stage is growth by gravitational capture, mainly of lighter elements, which is almost limited—as ter Haar shows—to the outer bodies only; this gravitational capture, mainly of the lighter elements, will still further accentuate the difference in the mean densities of the outer and inner condensations.

Weizsäcker calculates that the growth of condensations, practically up to the limit at which no small particles were left, would take about a hundred million years, which is comparable with the dissipation period of the gaseous envelope. The condensations formed in the roller-bearing eddies are the proto-planets. It is not clear, however, why there should be only one planet on each ring. Weizsäcker supposes that the condensations along one ring will come together 'in a manner difficult to visualize'; there would probably be interaction with the material in the wedge-shaped regions between the vortices, and a tendency for adjacent condensations to approach each other.

ter Haar finds that the condensation process gives a mass distribution which agrees with the actual distribution in the solar system as well as can be expected from general considerations. The only serious disagreements are that the mass of Mars is much smaller than the theory requires for a planet at the distance of Mars from the Sun, and the theory requires a planet between Mars and Jupiter; the asteroids, however, may be fragments of such a planet which has disrupted. The slowness of rotation of the inner planets can be adequately ascribed to tidal friction, caused by tides raised on them by the Sun.

The formation of the so-called 'regular' satellites can be attributed to an analogous process of condensation inside the planetary atmospheres; the relative distances of the satellites follow laws of the Bode type. The 'irregular' satellites, viz. the Moon, the two satellites of Mars, and the outer satellites of the major planets, are assumed to be condensation products that were captured by the planets at a later stage. Gravitational capture would not have played any significant role in the building up of the regular satellites because of their small mass, which accounts for the observational fact that their densities are higher than the densities of their primaries, but lower than the densities of the inner planets.

Weizsäcker's theory therefore offers a plausible explanation of the principal features of the solar system: the common direction of revolution and rotation of the planets and satellites; the essentially common plane of their revolution; the small inclinations of their equators to this plane; the slower rotations and higher mean densities of the inner planets relative to the outer planets; and, by and large, the mass distribution and Bode's law. It also provides a workable scheme for the loss of excess angular momentum, though the present very slow rotation of the Sun is not fully accounted for. No other theory yet proposed has been so successful. The theory is, moreover, fairly amenable to mathematical treatment, and many details can be investigated quantitatively. The catastrophic theories are not suitable for rigid mathematical treatment and at best can give only qualitative results.

In the investigation of the origin of the solar system, we labour under the disadvantage that we do not know whether planetary systems are exceptional. If the solar system had a catastrophic origin, planetary systems must be of extreme rarity; if, on the other hand, it was formed in the way Weizsäcker supposes, they should be of frequent occurrence, particularly in the Milky Way, where the interstellar clouds are abundant. The main limitation is that the temperature of the central star must not be too high, for otherwise condensation would not be possible; none of the very hot stars could be expected to have planetary systems. It is not beyond the bounds of possibility that observational evidence may eventually provide some information about the frequency of planetary systems. We should then have at least an indication whether or not such systems are of catastrophic origin.

The Muslim tradition in astronomy

H. J. J. WINTER

Muslim contributions to astronomy influenced the development of the science for roughly a thousand years. They were in two main fields. On the one hand, we are indebted to the Muslim astronomers for the astrolabe, an instrument which in its latest—and often exquisitely wrought—forms permitted many determinations to be made, for example, of the longitude of a planet in the ecliptic. On the other hand, they were responsible, through their great willingness to co-operate with scholars of other nations, for the wide diffusion of astronomical knowledge.

The Giralda Tower in Seville, completed *c.* 1195, was the first astronomical observatory in Europe. Yet it represented a Muslim tradition in observational technique which had its origins some four hundred years before, in the labours of those scholars working under the patronage of the early ʿAbbāsid caliphs such as Al-Manṣūr and Hārūn al-Rashīd. Among them were Ibrāhīm al-Fazārī, who first constructed astrolabes, his son Muḥammad, and two men who were responsible for the surveying of the site of Baghdad before its foundation in 762—namely Māshā'allāh (Messahalla), and Al-Manṣūr's own astrologer Al-Naubakht.

This glorious tradition, old as it then was, did not end in Seville: through Spain it influenced Europe, and in its eastern expansion it had a profound effect on Asian astronomy until the early eighteenth century. We can trace it in the Mongol observatories at Marāgha and Khānbaliq, in the observatory at Samarkand set up by order of the Turkish prince Mīrzā Ulugh Beg around 1420, and finally in the observatories at Delhi, Benares, Jaipur, and Ujjain, established by the Hindu Mahārāja Sawāī Jai Singh (1686–1743) at a time when the use of the telescope in Europe was rendering obsolete those instruments, often of exquisite workmanship, in which the Muslims took so much pride.

The principal instrument of medieval astronomy was the plane astrolabe. It is admirably and fully described by Willy Hartner in Vol. III of the great *Survey of Persian Art* edited by Arthur Upham Pope. The plane astrolabe or *astrolabium planisphaerium* (Arabic: *asturlāb saṭḥī*) consisted of a circular disk or *mater* (Arabic: *'umm*) with a raised rim and an axis or pin at its centre upon which rotated certain additional parts. These parts defined the functions of the front and the reverse of the astrolabe, which were essentially different though complementary. Thus, on the reverse of the instrument there rotated, over an angular scale, the *alidade* or sighter, which, when the instrument was suspended vertically, enabled the observer to read off the angular elevations or altitudes of heavenly bodies. The function of the reverse of the instrument was thus observational, and from it derived the mariner's astrolabe used by Columbus, and, later on, Hadley's quadrant. On the other hand, the front of the instrument was theoretical in function; it was in fact an elaborate calculating machine. The graduated rim of the disk or *mater*, the inner surface of which often had recorded on it the latitudes and longitudes of important astronomical centres, and the various additional disks (*ṣafā'iḥ*), supplying specialized information, which could be fitted over the central pin and allowed to rotate within the *mater*, facilitated a multitude of computations. These several additional disks, usually of thin brass, had inscribed on them almucantars,[1] azimuth circles, hour circles, etc., for various latitudes. One particular disk, of open-work design, called the spider or *rete* (Arabic: *ʿankabūt*) indicated the ecliptic, the signs of the zodiac, and, by means of pointed 'branches' or *shazāya*, the positions of certain fixed stars such as Vega and Arcturus.

This *ʿankabūt* leads us immediately to the principle of the front of the astrolabe, which now demands a few lines of explanation. The principle is that of stereographic projection, which, according to Neugebauer, may have been known as early as the time of Hipparchus (150 B.C.). Imagine a sphere, with a diametral plane through which the north-south line passes perpendicularly, and let there be drawn upon the surface of the northern hemisphere various circles; then if the points upon the circumference of one of these circles are joined directly to the south pole of the sphere, an imaginary cone will be formed whose section at the diametral plane will be a circle on that plane. This last circle and others similarly obtained are stereographic projections on the diametral plane. If

[1] From an Arabic term denoting parallels of altitude or circles parallel to the horizon.

FIGURE 1 – *An astrolabe presented to the Bodleian Library, Oxford, by William Laud, Archbishop of Canterbury. It probably dates from the early seventeenth century.* (× ½)

FIGURE 2 – *A finely wrought Moorish astrolabe of the thirteenth century.* (× ½)
(*Figures 1 and 2 reproduced from Gunther's* Astrolabes of the World.)

now we replace this sphere by the celestial sphere, and, on the assumption of a geocentric theory and circular planetary orbits, make stereographic projections upon the equator, the concentric circles so derived may be represented on a much reduced scale on the front surface of the astrolabe. In practice, the rim of the *mater*, for one single latitude, represented the projection of the Sun's orbit at winter solstice, and the other circles, such as the projection of the summer solstitial circle, fell within it. In this simplest case of a given latitude, the *mater* became a *ṣafīḥa* (singular of *ṣafā'iḥ*) bearing the appropriate stereographic projection of the heavens. The rim, divided in degrees, measured equinoctial time (right ascension). The *'ankabūt* represented the ecliptic, which is a circle touching the solstitial circles, and as it rotated about the central pin of the astrolabe, it represented the path of the fixed stars around the north pole of the heavens, such that a pointer on its rim which made contact with the scale on the rim of the *mater* gave, at the point of contact, the rotation of the ecliptic in right ascension. The 'off-centre' disposition of the *'ankabūt* is clearly seen in the figures. As an instance of the several uses to which the astrolabe was put, we may mention the determination of the approximate longitude of a planet in the ecliptic; using the *alidade* on the reverse of the astrolabe, the altitudes of the planet and of a fixed star were found experimentally, and this information then 'transferred' to the front of the instrument, the *'ankabūt* being set on the appropriate almucantar of the fixed star. The longitude of the planet was read from the degree of the ecliptic lying on the almucantar corresponding to the measured altitude of the planet.

Among other instruments known to the Muslims were the spherical astrolabe (*astrolabio redondo*), which comprised a celestial globe surrounded by a spider, and facilitated calculations in spherical trigonometry; the linear astrolabe, on which the dome of the heavens was projected in a straight line; various armillae, adaptations of the armillary sphere of the ancients, in which the poles of the heavens were represented, together with rings for the ecliptic and zodiac, and two colures or great circles dividing equinoctial and ecliptic into four equal parts at the equinoctial and solstitial points

of the ecliptic; instruments with sighting equipment consisting essentially of arcs of a circle, such as the quadrant and sextant, for finding the altitudes of celestial bodies; and improved versions of the sun-dial for measuring time. The great reputation of 'Alī ibn 'Īsā al-Aṣṭūrlābī (*c.* 830) of Baghdad and Damascus, and Al-Zarqūālī (*c.* 1080) of Córdova, in the making of astrolabes was well deserved. Fine astrolabes were still being produced in India in the days of the Moghul emperors.

A study of the shadows cast by the simple sundial or gnomon (*a*) when standing vertically upon a horizontal surface, and (*b*) when projecting horizontally from a vertical wall, laid the foundations, through such scholars as Al-Battānī (Albategnius, *d.* 929), and Abū-l Wafā' (*d.* 998), of modern trigonometry, and with Al-Ḥasan al-Marrākushī (*d.* 1262), became, in Morocco, an elaborate system of gnomonics.

The direction of development in Muslim instrument design is especially interesting. Whereas in the West accuracy was achieved by such measuring devices as the vernier and micrometer, the emphasis in the East was upon size and rigidity; Al-Khujandī (*c.* 1000) used a sextant of radius 57 ft. 9 in. and, according to John Greaves (*infra*), the great quadrant at Samarkand was of about the same height as St. Sophia in Constantinople, i.e. 180 ft, while Jai Singh, following the Muslim tradition, erected huge masonry instruments in India.

In the first half of the ninth century the *Almagest* of Ptolemy was translated into Arabic by the Jewish astronomer and physician Sahl (Rabbān) al-Ṭabarī, and the earlier Muslim observations made under the 'Abbāsid caliphate were mainly concerned with the verification of the information so derived, e.g. the value of the obliquity of the ecliptic. Ḥabash al-Ḥāsib, working at Baghdad in the reign of Al-Ma'mūn, measured time by the altitude of the Sun, and completed some astronomical tables.

The greatest of the Baghdad astronomers was Al-Battānī, who tested many of Ptolemy's results. He obtained improved values of the precession of the equinoxes and of the obliquity of the ecliptic and showed that the Sun's apogee had changed its position since the time of Ptolemy. He also constructed more accurate tables of the Sun and the Moon than were then in use.

Following upon the many astronomers of the 'Abbāsid period were those who worked under the patronage of the Buwayhid sulṭāns, the 'Umayyad caliphs of Córdova, and the Fāṭimids of Egypt. Ibn al-A'lam compiled accurate astronomical tables in the time of the Buwayhid 'Aḍud al-Dawla, and Ibn Yūnus completed in 1007, at the Cairo observatory, the Hakemite Tables. These researches were soon followed by the Toledan Tables edited by Al-Zarqālī, the reformed calendar of 'Umar Khayyām at Nīshāpūr, whose arrangement of 8 leap years in each period of 33 years is more accurate than that adopted in the Gregorian reform of the calendar in 1582, and the Sinjaric Tables of Al-Khāzinī of Merv. Such events leave no doubt as to the widespread influence of Muslim astronomy.

On the sacking of Baghdad in 1258 by the Īl-Khān Hūlāgū, grandson of the Mongol conqueror Ghengis Khan, Muslim astronomy became centred upon Marāgha in Adharbaijān, where a great observatory was established under the direction of Naṣīr al-Dīn al-Ṭūsī. This observatory, which is mentioned by Rashīd al-Dīn[1] in his *Universal History*, was of great importance as a cultural focus, in spite of its very short life.[2] It drew competent astronomers from various and distant parts of Asia and was equipped with specially fine instruments, not surpassed for more than three centuries by any instruments in Europe. Among Al-Ṭūsī's assistants were Al-'Urḍī of Damascus, Fakhr al-Dīn from Mūṣul, Al-Khalāṭī from Tiflīs, Najm al-Dīn Dabīrān from Kazvīn, and Ibn al-Fūṭī (Al-Shaibānī) from Baghdad. Others who spent some time there were Abū-l Faraj (Barhebraeus), who was primate of the Eastern Jacobites, and Muḥyī al-Dīn al-Maghribī, an astronomer from western Islām, while Chinese scholars, such as Fu Meng-chi, were said to have been sent there to study on the orders of Hūlāgū. The more important Greek writings on astronomy and geometry were translated at the Marāgha observatory, and some of them have survived only in the Arabic version. These translations had a great influence on the development of Arabic astronomy.

Sino-Persian collaboration in astronomical studies is a special feature of the Yüan (Mongol) Dynasty during the latter part of the thirteenth century, when the Central Asian caravan routes were under the Mongol control. Although Hūlāgū had died in 1265, the astronomical tables—Zīj-i-Īlkhānī—begun by Al-Ṭūsī at the Great Khān's request soon after the fall of Baghdad, saw completion around 1272, and the early stages of this compilation no doubt inspired Kublai Khān, who had been on friendly terms with his brother Hūlāgū and perhaps wished to emulate him, to set up a

[1] Physician to Hūlāgū's successor Abaqā Khān.
[2] It is said to have been in ruins by 1340.

further observatory at the new capital city of Khānbaliq in China. We have names such as 'Isā the Mongol (Ai-Hsieh), Jamāl al-Dīn (Cha-ma-li-ting), and Kuo Shou-Ching to remind us of this spirit of co-operation. Jamāl al-Dīn left Marāgha soon after the death of Hūlāgū and reached Khānbaliq in 1267, carrying with him, according to the book Yüan Shih, drawings, or perhaps models, of seven Muslim instruments, and Willy Hartner thinks that an extant armillary sphere dated 1279 was made by Kuo Shou-Ching in accordance with a design supplied by Jamāl al-Dīn. Kuo Shou-Ching also probably introduced Muslim spherical trigonometry, on which subject Al-Ṭūsī had written a monumental treatise, *Kitāb shakl al-qaṭṭā'*, to Chinese mathematicians. The Muslim tradition, however, seems never to have made a strong impression in China, the two surviving Mongol instruments having their own particular circular measure of 365¼ divisions, with 100 subdivisions, each divided again by 100. In fact, China received again, from the Jesuits in the seventeenth century, precisely the same information which it had tended to neglect in the thirteenth—information which had proceeded westwards from the same Muslim origins and had reached European scholars through the monumental *Libros del saber de astronomía* (*c.* 1276), of Alfonso X of León and Castile, and the Alphonsine Tables compiled under his direction (*c.* 1272) by the Hispano-Jewish scholars Judah ben Moses and Isaac ibn Sid.

Yet it was not in Spain alone that the Muslim astronomy flourished. There was a school at Samarḳand in the time of Tīmūr-Lang which burst forth into remarkable activity under the enlightened patronage of his grandson Mīrzā Ulugh Beg (*b.* 1394), who built an observatory there. From 1420, until this prince's assassination by his son in 1449, fine masonry instruments of great size were erected, and the observations made with them were used in the compilation of the Samarkand Tables entitled Zīj Ulugh Beg which appeared in 1437. Ulugh Beg's star catalogue was of high accuracy for its time, and is noteworthy as the first essentially new catalogue since Hipparchus. Both the Īlkhānian and Samarkand Tables had tremendous influence; portions were rendered into Latin by John Greaves, Savilian Professor of Astronomy at Oxford in the time of Charles I, and had their due effect upon Western astronomy. Turkish influences were strong at Samarkand. Ulugh Beg and the second director of his observatory, Qāḍī Zāde al-Rūmī, were Turks, while the astronomer Al-Qūshchī worked both at Samarkand and at Constantinople. Excavations around the great quadrant at Samarkand in 1909 brought to light metal rails and a graduated marble scale.

Jai Singh II of Jaipur, and his son Madhu Singh, bring to an end this long and illustrious tradition, stretching over almost a millenium of Islamic history. Though a Hindu, as was his chief assistant Jagannāth, Jai Singh may be regarded as the successor to the astronomers of the Moghul period in that, in spite of a knowledge of both European and Hindu astronomy, he followed closely the Muslim methods, set about improving the Muslim astronomical tables, and copied the instruments of Ulugh Beg. Jagannāth was employed because he knew Arabic, and he produced a Sanskrit translation from the Arabic version of Ptolemy's *Almagest*. Not unmindful of European researches (he sent Father Figueredo to Portugal *c.* 1728 and was visited by Father Boudier in 1734, while he was acquainted with the work of Flamsteed (1646–1720), La Hire (1640–1718), and their predecessors), Jai Singh nevertheless followed mainly, in the erection of his observatories at Delhi (1724) and other centres, and in the compilation of his new tables, the Muslim line of investigation exemplified by the technique of such astronomers as Al-Ṭūsī and Ulugh Beg.

BIBLIOGRAPHY

GREAVES, JOHN. 'Ulugh Beigh: Longitudines et Latitudines . . . Stellarum.' Oxford. 1648.

Idem. 'Astronomia quaedam ex traditione Shah Cholgii Persae . . .' London. 1650.

GUNTHER, R. T. G. 'Early Science in Oxford' (Vol. 5). Chaucer and Messahalla on the Astrolabe. Oxford University Press, Oxford. 1929.

HARTNER, W. *Isis*, **41**, 184, 1950.

KAYE, G. R. 'Archaeological Survey of India' (Vol. XL). The astronomical observatories of Jai Singh. Government Printing Office, Calcutta. 1918.

MICHEL, H. M. 'Traité de l'astrolabe.' Gauthier-Villars. Paris. 1947.

MINORSKY, V. 'Encyclopaedia of Islam' (Vol. 3). Maragha. Brill, Leiden; Luzac, London. 1930.

NEUGEBAUER, O. *Isis*, **40**, 240, 1949.

POPE, A. U. 'Survey of Persian Art' (Vol. 3), 2530–54. Oxford University Press, Oxford. 1939.

SARTON, G. 'Introduction to the History of Science' (Vol. I). Williams and Wilkins, Baltimore. 1927.

SCHOY, C. 'Über den Gnomonschatten und die Schattentafel.' Hanover. 1923.

SUTER, H. 'Die Mathematiker und Astronomen der Araber und ihre Werke.' (Nachträge) Teubner, Leipzig. 1900, 1902.

Some smaller whales

H. BOSCHMA

As many of the existing figures of whales and dolphins are inaccurate, it has been the policy of the Leiden Museum of Natural History to obtain coloured illustrations of a number of stranded animals of the group, based on accurate measurements. Whenever there became available—in a good state of preservation—a cetacean that was of scientific interest, an accurate oil painting was made by the late Mr M. A. Koekkoek. Some of these are reproduced in the present article, showing the left side, the lower surface, the head in dorsal view (and in one case one of the flippers), of a Pygmy Sperm Whale, a New Zealand Scamperdown Whale, and two Bottle-nosed Whales, stranded between 1925 and 1931 on the Dutch coast.

The Pygmy Sperm Whale (*Kogia breviceps*) in general appearance is dolphin-like, but the mouth terminates behind the tip of the snout. The teeth are normally confined to the lower jaw. In the Pacific and Indian Oceans the species is not uncommon around Australia and New Zealand, and it is known from the waters of South Africa, India, Ceylon, Indo-China, and the East Indies. It has been reported near Japan, and there are two records for the Eastern Pacific (Mexico and Peru). In the North Atlantic, twenty strandings on the American coast, from Florida to Nova Scotia, are listed by Allen [1], while on four occasions the species came ashore in European waters. Delage [2] reported upon the first of these, a male, stranded near Roscoff in Brittany in 1905. The head was brought to the *Bureau de la Marine*; the body was left for the dogs to eat their fill. What remained, together with the head, formed the subject for elaborate studies by Le Danois [3, 4]. In the last of these publications the author remarks that in 1910 a Pygmy Sperm Whale came ashore on the Ile d'Oléron; of this animal the museum at La Rochelle was unable to obtain more than the skin, which was afterwards stuffed. The third European specimen, the one figured here, was found on the beach at Noordwijk aan Zee in Holland in 1925. Van Oort [5] remarks that the carcass was in a comparatively fresh state, only slightly mutilated by destructive hands. It was a female of a length of 2·95 m. The colour may be described as follows. Back, steel blue, with a partial tendency to slate grey, gradually becoming lighter on the sides. Under surface, ivory white from the tip of the lower jaw to slightly behind the vent. Upper surface of the flippers, dark blue; under surface whitish. Under parts of the tail and flukes, a lighter blue than the remainder of the tail. In the white of the lower surface there were a number of brownish spots which may have been caused by the beginning of decomposition in the skin. The specimen dealt with here is the only one in which a decidedly bluish tinge of the darker parts was to be observed. As a rule the darker parts of stranded Pygmy Sperm Whales are described as black or jet-black, exceptionally as slatey grey. In the literature on the subject the colour of the belly has been described as white, dirty white with a tinge of yellow, or pinkish.

According to information kindly supplied by Dr F. C. Fraser, a fourth specimen, stranded on the Portuguese coast, is preserved in a stuffed condition in the marine institute at Dafundo near Lisbon.

The shape of the dorsal fin of the Pygmy Sperm Whale is subject to considerable variation, as already stated by Allen [1] and by Hale [6]. In the figure in Norman and Fraser [7], this fin is inconspicuous; in the specimen figured in Fraser and Parker (by Simon) [8] it is long and pointed. The animal represented in figure 1 had a low, blunt fin.

In all the Pygmy Sperm Whales of which the blowhole has been described this organ is stated to be in an oblique position. In the specimen dealt with here this point of asymmetry was not apparent.

The New Zealand Scamperdown Whale (*Mesoplodon grayi*) was observed for the first time in the Chatham Islands, where a school of about twenty-eight was stranded in 1874. Three heads were sent to Julius von Haast, the director of the then recently founded Canterbury Museum at Christchurch. He described the animal as a new species [9], the outstanding specific character of which was a row of minute teeth partially protruding from the gum on each side of the upper jaw, and varying in number from seventeen to nineteen. Each row began just behind where, in the lower

jaw, a fairly large tooth is situated in each ramus. Shortly afterwards, von Haast [10] received four specimens from the New Zealand coast, each again with distinct rows of minute teeth. Later on, many specimens came into the collections of various museums, and it has been observed, whenever a specimen of the New Zealand Scamperdown Whale (a name that came into use soon after the description of the species) could be studied in the flesh, that the upper jaw proved to possess a row of minute teeth on each side.

Up to 1950, *Mesoplodon grayi* was known to occur in the seas around New Zealand, New South Wales, Victoria, South Australia, South Africa, and Patagonia.

FitzSimons [11] lists Sowerby's Whale (*Mesoplodon bidens*) among the mammals of South Africa, considering the animal stranded near Port Elizabeth in 1910 as the first recorded specimen of that species from the Southern Seas. In the volume cited, there is a photograph of the stranded specimen and one of its skull in side view. In 1910 these same photographs were sent by FitzSimons to London, where Lydekker [12] correctly identified the specimen as *Mesoplodon grayi*, pointing to the fact that the teeth in the lower jaw are distinct from those of *Mesoplodon bidens*.

Sowerby's Whale and the New Zealand Scamperdown Whale have one character in common that may easily lead to misidentification: the teeth in the lower jaw occupy exactly the same place, and as far as they protrude over the margin of the jaw they may have a similar appearance. In the Leiden Museum there is a skeleton of a female Beaked Whale of 4·60 m, stranded near Loosduinen on the Dutch coast in 1927; on account of the position and the shape of the teeth in the lower jaw it was provisionally identified as Sowerby's Whale (*Mesoplodon bidens*), but it eventually proved to be a specimen of the New Zealand Scamperdown Whale (*Mesoplodon grayi*). The skull has the typical characters of the latter species, and, moreover, on each side of the upper jaw there is a row of twenty-two small teeth—for the greater part embedded in the gum, but with their tips freely protruding (Boschma [13]). Fortunately the whale arrived on the beach in mid-winter in a completely undamaged state, so that an accurate coloured picture could be made. The latter is reproduced as figure 2, and is the only picture in existence of the complete animal. The colour of the specimen is black to dark slate grey on the back, gradually merging into a brownish grey on the sides. The ventral surface is of a light grey with a brownish tinge, with the exception of a broad darker median area, which becomes mottled anteriorly and vanishes in the region of the flippers. The flippers and the tail-flukes on both sides are very dark grey to black, the edges of the flippers having a lighter border. The lower jaw and the throat are of a very light grey, almost white in some places. On the edges of the upper jaw, and around the navel, the genital aperture, and the vent there are whitish lines. On the sides there are a single white streak and several smaller white patches which ought possibly to be regarded as scars. In New Zealand specimens, according to von Haast [10], the colour of the back is black, getting a little lighter near the tail, where it assumes a dark slate tint; the lower surface is reddish brown, assuming a blacker hue on both sides near the tail. The animal stranded near Port Elizabeth was jet-black all over (Lydekker [12]); Cabrera and Yepes [14] also describe the colour as black.

It must be admitted that our knowledge of the distribution of the Beaked Whales, especially as far as concerns the species of the genus *Mesoplodon*, is very scanty. The commonest species, Sowerby's Whale (*Mesoplodon bidens*), is restricted to the North Atlantic; it has been recorded from the European coasts as well as from the North American. True's Beaked Whale (*Mesoplodon mirus*), originally found on the Atlantic coast of North America, has been reported three times in British waters since 1917 (Harmer [15]). Another rare species, *Mesoplodon europaeus*, was described from a specimen found floating at the entrance to the English Channel; later it became known from the North American Atlantic coast. *Mesoplodon bowdoini* was known until recently only from two skeletons found on the coast of New Zealand (Fraser [7]); Hubbs [16] gave an account of a specimen stranded in Southern California. There is one species of the genus (*Mesoplodon densirostris*) that appears to have a random distribution, as the seven known specimens are from such widely separated localities as the Seychelles, Lord Howe Island, South Africa, Massachusetts, New Jersey, and Madeira. The few other species of the genus seem to have a rather restricted distribution.

In the Bottle-nosed Whale (*Hyperoodon rostratus*) the snout is more sharply defined from the remainder of the head than in any of the other Beaked Whales, and consequently the head has a prominent 'forehead' that, especially in old males, is strongly bulging. The maximum size is about 9 m for males and slightly over 7 m for females.

The colour of the Bottle-nosed Whales stranded

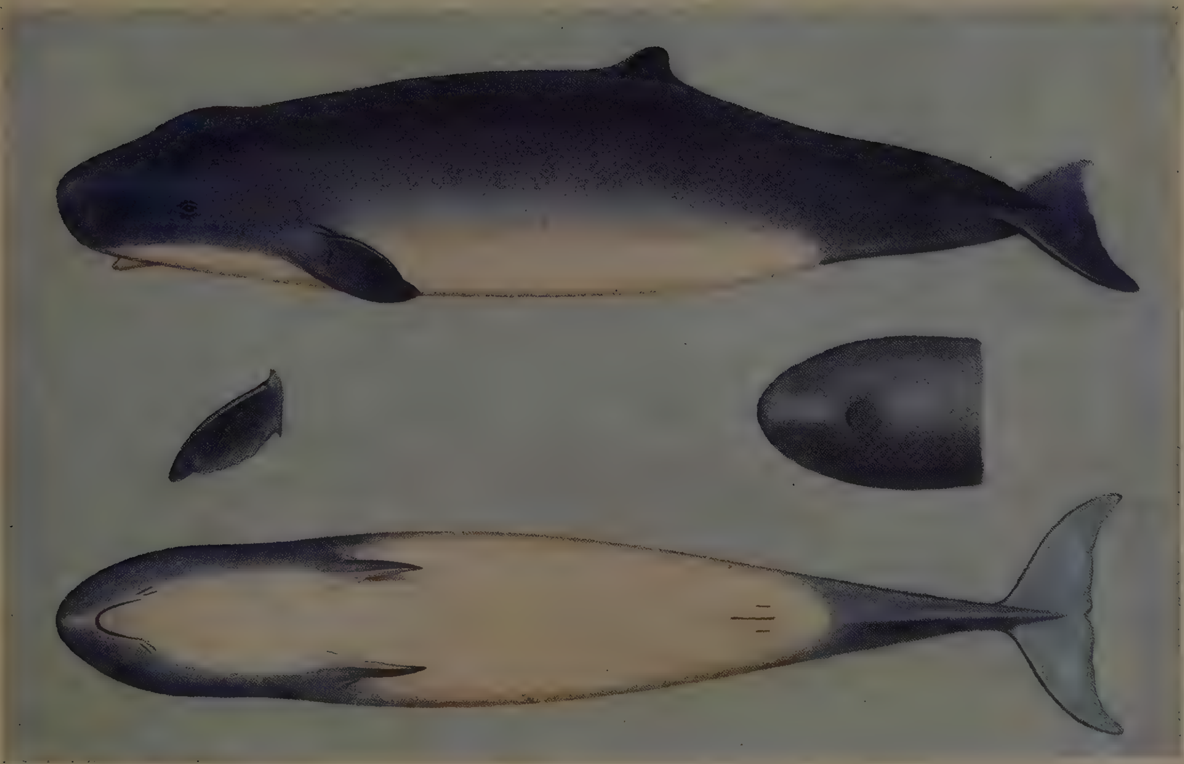


FIGURE 1 – *Pygmy Sperm Whale* (Kogia breviceps), *adult female, total length* 2·95 *m. Noordwijk aan Zee,* 1925. *Showing left side, lower surface of body, dorsal view of head, and one flipper.*

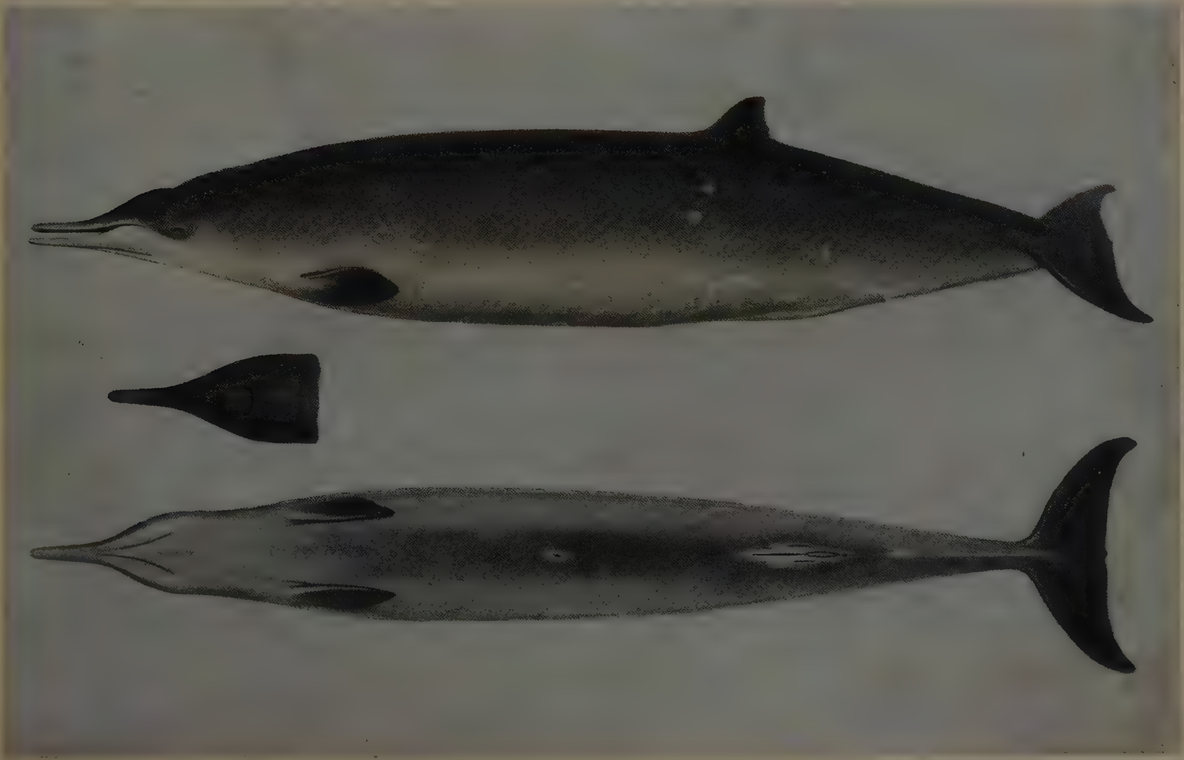


FIGURE 2 – *New Zealand Scamperdown Whale* (Mesoplodon grayi), *female, total length* 4·60 *m. Loosduinen,* 1927. *Showing left side, lower surface of body, and dorsal view of head.*

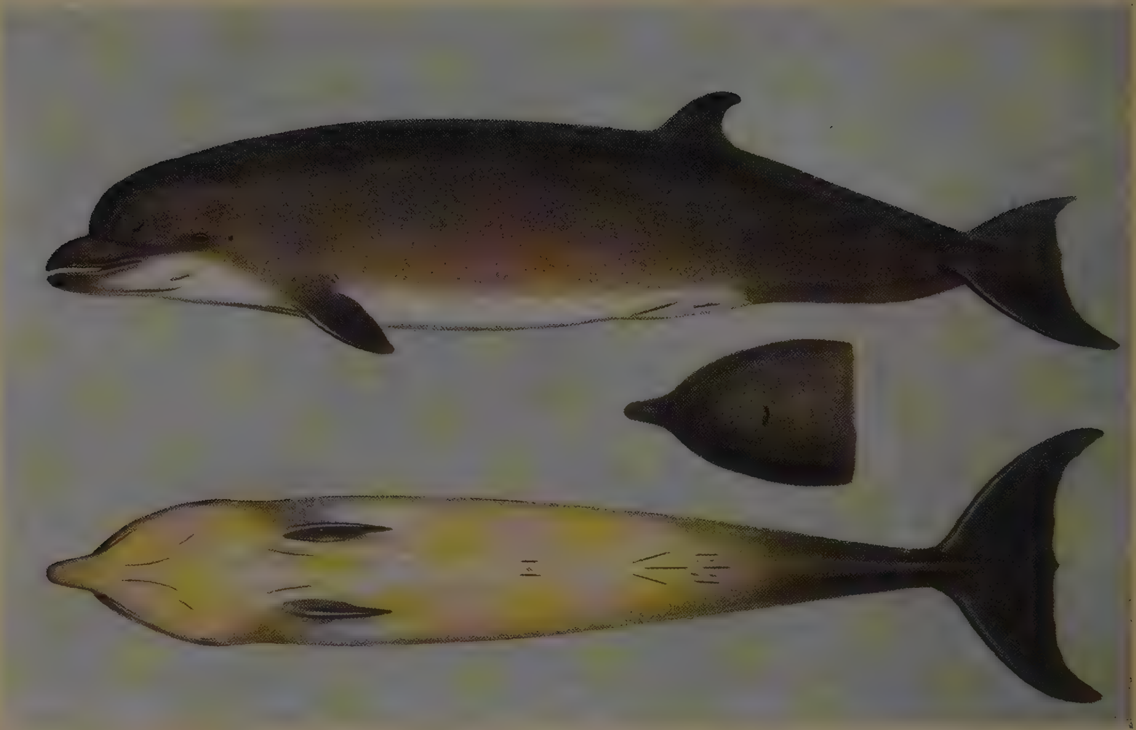


FIGURE 3 – *Bottle-nosed Whale* (Hyperoodon rostratus), *young male, total length* 4·20*m. Off Texel,* 1927. *Showing left side, lower surface of body, and dorsal view of head.*

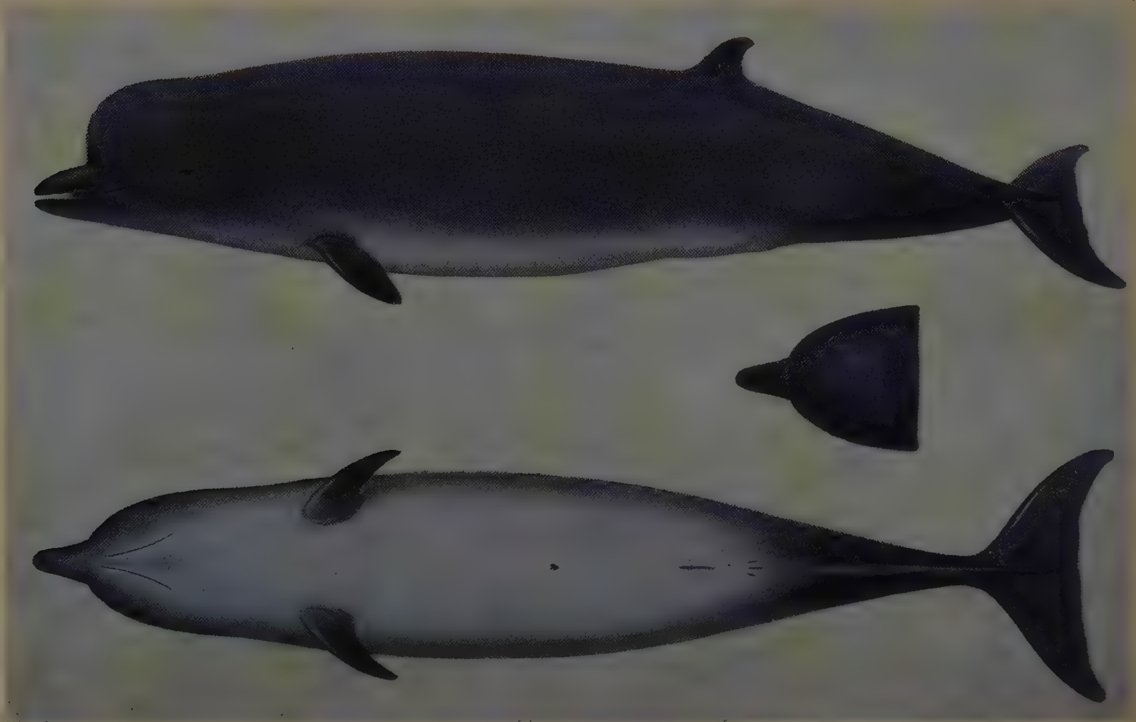


FIGURE 4 – *Bottle-nosed Whale* (Hyperoodon rostratus), *male, total length* 5·29*m. Near Waarde,* 1931. *Showing left side, lower surface of body, and dorsal view of head.*

on various European coasts up to the later part of the nineteenth century was almost invariably described as blackish grey. The under parts were generally stated to be of a somewhat paler colour. At present, it is an accepted view that the colour changes with age. David Gray [17], commander of the whaling steamer *Eclipse*, who captured numerous Bottle-nosed Whales, gives the following account: 'They vary in colour from black in the young to light brown in the older animals. The very old turn almost yellow, the beak and front of the head being quite white, with a white band round their necks; all of them are greyish-white in the belly.' Substantially, this statement is corroborated by Axel Ohlin (see Millais [18]). In later years, however, specimens were obtained that formed exceptions to the statement quoted above. Harmer [19], when considering a young specimen with a good deal of white, and a much larger one of an almost entirely black colour, came to the conclusion that 'the alteration in colour is not always so regularly progressive as it has been described to be by previous observers.' In this connection two young Bottle-nosed Whales from the Dutch coast are of interest. One of these, a young male of 4·05 m, stranded near Egmond, was described by Junge [20] as having along the sides a distinct sepia-brown area between the black of the back and the yellowish white of the belly. Moreover, Junge refers to the young male specimen (figure 3), captured off Texel in 1927, length 4·20 m. In this animal the entire back was dark greyish to chestnut brown; the flippers and the tail had the same colour. Towards the lower surface the sides gradually turned into a lighter brown, which passed to yellowish white on the under parts. Here the light colour extended from the under side of the head to the region of the vent; it continued as a narrow median light-brown stripe on the tail. On the other hand, a much larger young male, stranded near Waarde in 1931, length 5·29 m (figure 4), shows in every detail the colouring that is regarded as characteristic of young animals. The back and the greater part of the sides are dark slate grey to black, and the same colour is found on the flippers and on the flukes. The under surface, from the throat to the region of the vent, is grey.

These two Bottle-nosed Whales (figures 3 and 4) show some further interesting points. Though both are comparatively young, they already show distinct differences in the shape of the head. In the brownish younger specimen the 'forehead' is far less bulging than in the blackish older specimen. The peculiar development of the head in the male Bottle-nosed Whale therefore starts at a comparatively early age. Moreover, the two specimens in ventral view show distinctly the two converging throat grooves that are characteristic of all Beaked Whales. It has been observed that in embryos four of these throat grooves may occur. It is interesting that the brownish younger specimen shows, next to the pair of conspicuous throat grooves, a pair of shorter grooves of the same kind, undoubtedly the rudiments of originally more fully developed grooves.

Many more observations are needed before the variation in colour in cetaceans (and, as a matter of fact, the variation in many other characters) can be sufficiently known.

REFERENCES

[1] ALLEN, G. M. *Field Mus. Publ.* (*Zool. Ser.*), **27**, 17, 1941.
[2] DELAGE, Y. *C. R. Acad. Sci. Paris*, **142**, 258, 1906.
[3] LE DANOIS, E. *Arch. Zool. exp. gen.*, **6**, 149, 1910.
[4] *Idem. Ibid.*, **6**, 465, 1911.
[5] VAN OORT, E. D. *Zoöl. Meded.*, **9**, 211, 1926.
[6] HALE, H. M. *Rec. S. Aust. Mus.*, **8**, 531, 1947.
[7] NORMAN, J. R. and FRASER, F. C. 'Giant Fishes, Whales and Dolphins,' 2nd edition, Putnam, London, 1948.
[8] FRASER, F. C. and PARKER, H. W. 'Guide for the Identification and Reporting of stranded Whales, Dolphins, Porpoises and Turtles on the British Coasts.' British Museum, London, 1949.
[9] VON HAAST, J. *Proc. zool. Soc. Lond.*, 7, 1876.
[10] *Idem. Ibid.*, 457, 1876.
[11] FITZSIMONS, F. W. 'The Natural History of South Africa—Mammals.' Vol. 4. Longmans, Green & Co., London, 1920.
[12] LYDEKKER, R. *Proc. zool. Soc. Lond.*, 420, 1911.
[13] BOSCHMA, H. *Proc. K. Ned. Akad. Wet.*, **53**, 775, 1950.
[14] CABRERA, A. and YEPES, J. 'Historia Natural Ediar. Mamíferos sud-americanos.' Compañía Argentina de Editores, Buenos Aires. 1940.
[15] HARMER, S. F. 'Report on Cetacea stranded on the British Coasts from 1913 to 1926.' No. 10. British Museum, London, 1927.
[16] HUBBS, C. L. *J. Mammal.*, **27**, 242, 1946.
[17] GRAY, D. *Proc. zool. Soc. Lond.*, 726, 1882.
[18] MILLAIS, J. G. 'The Mammals of Great Britain and Ireland,' Vol. 3. Longmans, Green & Co., London. 1906.
[19] HARMER, S. F. 'Report on Cetacea stranded on the British Coasts during 1917.' No. 5. British Museum, London, 1918.
[20] JUNGE, G. C. A. *Levende Nat.*, **41**, 16, 1936.

The form of coral reefs

C. M. YONGE

The structure of coral reefs is the result of the combined action of several powerful forces—especially the growth of the living organisms and the action of wind-driven seas on exposed surfaces. Consideration of the relative contributions of these forces explains the curious ring-shaped structure of the oceanic atolls; it further suggests strongly that this is indeed the only possible form in which coral islands could be built up and maintained in mid-ocean.

Living coral reefs are associations of marine animals and plants found only within shallow tropical seas where temperatures seldom fall much below 20° C. They are thus largely confined to the tropics, although extending beyond these limits where there are outflowing warm currents, as in the Atlantic around Bermuda. The most conspicuous organisms on most reefs are the stony corals, or Madreporaria, animals essentially similar to sea anemones, but with a calcareous skeleton, from the surface of which they expand, and with protective cups or calices into which they are able to withdraw. Massive, branching, foliaceous, or encrusting colonies are formed according to the species, modified sometimes by environmental conditions. These are reef-building corals, to be distinguished from related species that inhabit cold or deep seas. With them live representatives of all the great groups of marine animals. There are allied soft corals (Alcyonacea) and horny corals (Gorgonacea), the latter especially numerous on West Indian reefs, also numerous molluscs, worms, and crustaceans, with echinoderms, such as star fishes, sea-urchins, and many types of sea cucumber or *bêche-de-mer*. Smaller animals abound in crevices and under stones. Plants are no less important. Seaweeds like those on temperate shores occur—usually with limited life, one species succeeding another throughout the year—but both green and red calcareous algae form permanent growths of prime importance in the maintenance of reefs.

A reef is geologically a mass of limestone formed from the skeletons of corals, mingled with shells ranging from those of giant clams to the spirally chambered shells of minute foraminiferous protozoa. Only the surface of this mass with its fissures is inhabited. Coral skeletons and large shells may be regarded as bricks, and smaller shells with broken fragments as rubble. Unaided, these could form no secure reef. Essential cement is provided by plants, the pink calcareous nullipores, largely *Lithothamnion*, which form an encrusting ridge, as shown in figures 1 and 10, where the surf is great. The green calcareous weed, *Halimeda*, is often abundant in shallow water, forming branching growths. Its whitened fragments are common in coral sands.

The great mass of a reef is nourished from the surrounding sea. From this the corals obtain the microscopic animals on which they feed, and also the calcium salts which, incorporated in their skeletons, form the substance of the reef. The living reef is an entity, its varied inhabitants mutually interdependent—for food, for protection, for surface of attachment, and in some cases for exposure to surf or even periodically to the air when the tide retreats. Many animals as well as the calcareous algae add to the mass of the reef, but almost as many destroy it. By mechanical or chemical action the rock is bored by a variety of molluscs, worms, sea-urchins, sponges, and even barnacles, while some plants ramify through the coral rock. Coral fragments are constantly ground smaller by repeated passage through the bodies of *bêches-de-mer*. The sea is the greatest agent of erosion. Crossland [1] maintained that around Tahiti these destructive forces were the greater, and that the reefs were receding, but in many areas they certainly maintain themselves and increase.

The growth and eventual form of a coral reef represents the outcome of a complex of interacting factors—some intrinsic, such as the rate and nature of growth in different corals, others environmental and so extrinsic. Description may suitably begin by consideration of the simplest case, that of fringing reefs. Such formations occur in shallow coastal waters off continents and rocky islands. The initiation of such a reef would follow the settlement of coral larvae, and the formation of the first polyp and skeletal cup, to be followed by others as the colony grew. Growth will tend to be upward towards the source of light. This positive reaction to light has been demonstrated in a variety of ways, most simply by suspending a

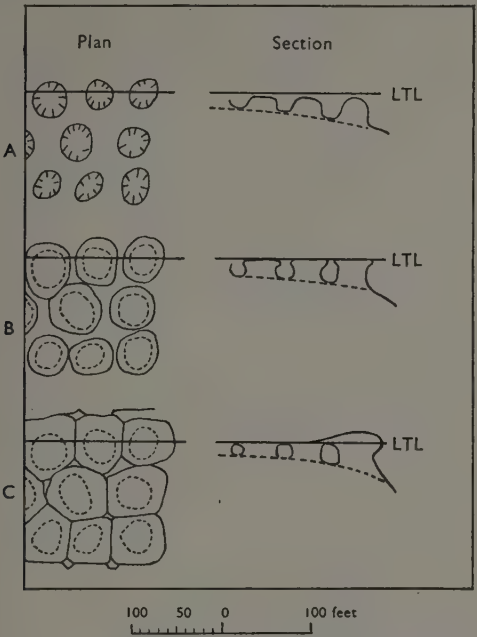


FIGURE 1 – *Bikini Atoll. Diagrams illustrating formation of room and pillar structures on crest of exposed reefs.* A, *bosses of* Lithothamnion; B, *shelving and lateral growth in surf zone;* C, *development of new reef floor, with room and pillar structure below.* LTL, *low tide level.* (*After Tracey, Ladd, and Hoffmeister.*)

broken branch of coral horizontally beneath the surface, when the new growth from the broken end will turn towards the light [2].

Reef-building corals live only in illuminated waters, never much below 25 fathoms. This dependence on light is possibly due to the invariable presence within their tissues of innumerable unicellular brown algae, some 0·01 mm in diameter, known collectively as zooxanthellae. Up to 7400 have been counted within a coral larva 1 mm long. The significance of the relationship between coral and plant symbiont has long been debated, but there is now no doubt that the plants are valueless as food to the corals, being rejected from the tissues, not consumed, when the corals are starved of animal prey [3]. The oxygen produced in photosynthesis by the plants has been claimed to benefit the corals [4], but this remains unproved, the water around corals being usually well oxygenated. However, when building up proteins from carbohydrates, the zooxanthellae utilize all nitrogenous and phosphoric waste, mainly ammonia and phosphates, produced by the corals [3]; hence these, with other end-products of metabolism such as carbon dioxide, are automatically removed from the animal tissues. Corals have no excretory organs, but the plants serve as such, so increasing the efficiency of the corals. This is immaterial to individual coral colonies, which can exist without zooxanthellae, but it may be of vital importance to communities of reef-building corals by conferring those additional powers of growth and repair which permit the establishment and maintenance of reefs.

Whatever the cause, corals grow upward and eventually reach the surface. As they do so, conditions on the two surfaces become increasingly different. Waves approaching a coast are deflected so that they come in at right angles to it. Hence the seaward surface of the growing reef will encounter the incoming swell whereas the landward surface will be bathed by calm but turbid waters. The upper surface, when it finally breaks the surface of the sea, will be exposed to the air when the tide is out. We are thus, as shown in figure 2, presented with a community which, in consequence of its own growth, creates a variety of environments—an exposed seaward surface, a reef crest where the surf breaks, a reef flat behind this, merging where wide enough into a zone of shallow sheltered water where sediment collects. The reef

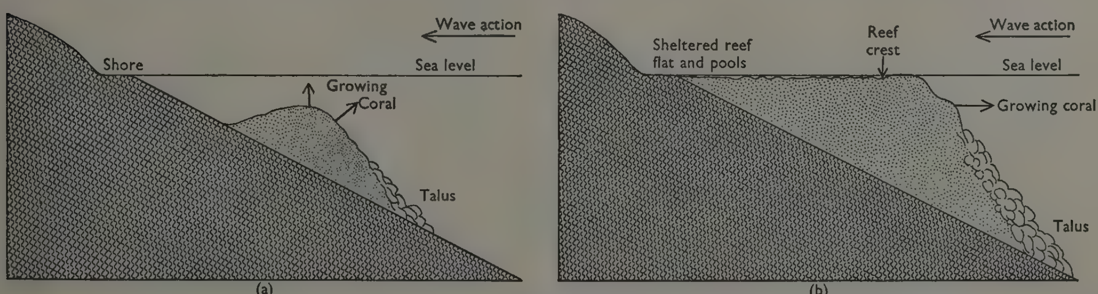


FIGURE 2 – *Diagram showing stages in the formation of a fringing reef.* (a), *mass of coral* (*stippled*) *before reaching surface;* (b), *fringing reef extending seaward.*

crest and flat, and the upper surface of coral masses further inshore, will all experience some degree of exposure.

Thinking for a moment in terms of evolutionary history, we may envisage corals as evolving in shallow seas and not initially forming large colonies. But within the tropics, just possibly owing to establishment of symbiosis with zooxanthellae, vigour of growth increased, great colonies were formed, and the reef-mass eventually reached the surface. Later success might be attributed to adaptation of particular genera or species for life within the different environments that the growth of the reef-mass itself brought into being. This would include acquisition of some of those functional adaptations which enable shore-dwelling animals to withstand extremes of temperature and salinity, and the effect of alternate exposure and submergence.

Modern reef-building corals are so adapted. Some species live only at certain depths below the surface, others can withstand shore conditions, but in varying degrees so that corals occur in zones from below low-tide level upward [5]. Some can withstand the full force of the Pacific surf; most of these have massive skeletons, although branching colonies of *Acropora* also occur [6]. Delicate branching and foliaceous species grow in the lee, while on the *Lithothamnion* ridge live flattened colonies, offering no resistance to the rush of waters. The most specialized corals live free on sand. These include the mushroom coral, *Fungia* [7], with allied genera, and, in the Atlantic, the simple brain coral *Maeandra areolata* [8]. All begin life attached, and then become freed when, at the mercy of water movements, they are deposited with other fragments in the lee and so find themselves on sand. They counter the dangers of this unstable substratum by uncovering themselves when buried, as shown in figure 9, and, at any rate in *Fungia*, by righting themselves if turned over.

Other corals are modified by prevailing conditions. Initially, every difference in coral growth was described as a separate species; later certain field workers, especially Wood-Jones [9], went to the other extreme of claiming that coral species are few, each having many growth forms. Modern opinion lies intermediately; there are many species, but some are plastic, the eventual form assumed depending on the environment. The success of reef-building corals would appear to be due to the existence of some species highly adapted for life in particular environments, and of others which can live under a variety of conditions because they can adapt themselves to them.

The different environments created by the upward growth of a reef are thus occupied. When exposure to the air halts further growth in this direction, the reef continues to increase, most actively along a zone a few fathoms down on the seaward slope. This represents the growing edge, and below it extends a talus of broken fragments. The reef invariably grows out against the force of the waves. Even when an isolated island, such as the extinct volcano of Mer Island in the Torres Strait shown in figure 3, is encircled by a fringing reef, this is much wider on the weather side which faces the south-east trade winds. On the lee of the island, the reef is very

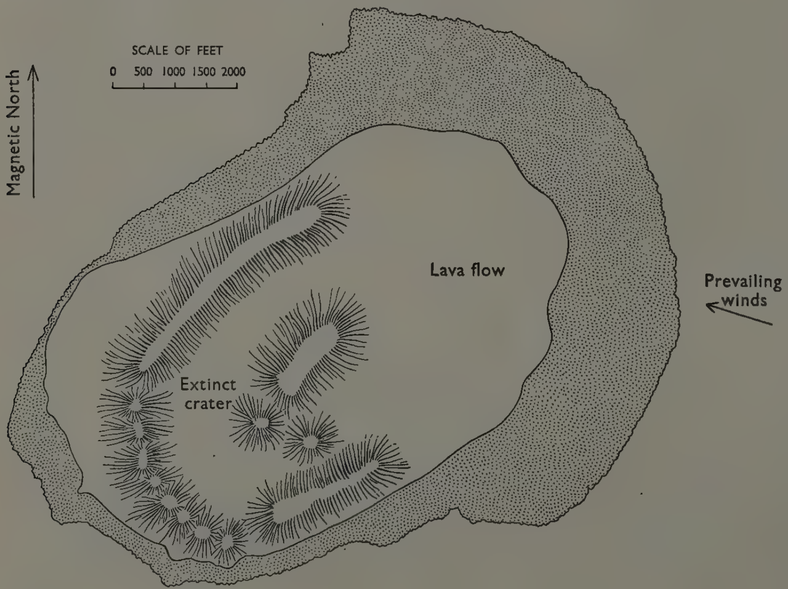


FIGURE 3 – *Outline map of Mer Island, showing much greater extent of fringing reef (stippled) on eastward (weather) side of island. (Modified after Mayor.)*

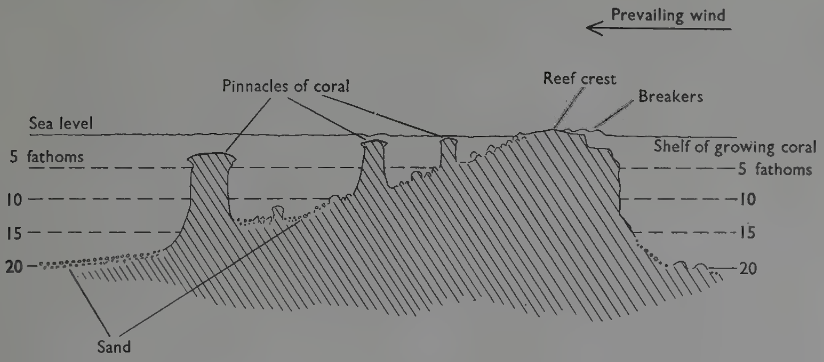


FIGURE 4 – *Section through an outer barrier reef, showing relation of form to prevailing winds.* (*Modified after Paradice.*)

narrow and composed of delicately branching stagshorn coral.

Paradice [10] described the orientation of reefs in relation to the prevailing seas in an account of one of the outer reefs of the Great Barrier. As shown in figure 4, he observed the abrupt descent into deep water on the side exposed to the Pacific surf, the shelf of growing coral a few fathoms below the surface, the reef crest cemented with *Lithothamnion*, and the gradual slope on the lee, with the growth there of pinnacles of living coral often mushroom-shaped owing to luxuriant growth at the summit. Between them the bottom is of coral sand. Such conditions were repeatedly encountered during the course of the Great Barrier Reef Expedition, and have been more fully analysed and described elsewhere [6].

Further indication of the forces involved is provided by description of the sheltered island reefs found in the channel between the Great Barrier and the mainland and exemplified by Low Isles, the headquarters of the Great Barrier Reef Expedition. As shown in figure 5, the reef is oriented in relation to the south-east trades. The seaward side is convex, is consolidated but with no *Lithothamnion* ridge, and descends quickly into deep water. On the lee it is concave, with a protected anchorage, while a small sand cay (insular bank) is formed from material which is carried over or swept around the reef. Off-shore are many coral pinnacles (figure 8) arising from water of slowly increasing depth. The general picture resembles that for barrier reefs, but the seas, owing to protection within the barrier, are much slighter. Possibly for this reason, material thrown on to the surface of island reefs accumulates there, and a variety of formations occurs, each comprising some type of calcareous debris and all moulded by the exclusive action of wind and waves. It is maintained by many that only after elevation, or fall in sea level, can material accumulate on the surface of a reef, but some measure of shelter is also essential. Sand cays never occur on outer barrier reefs, but may do so on inner reefs.

FIGURE 5 – *Low Isles, North Queensland. Outline map, showing form of the reef and the various formations built up on its surface.* (*After Stephenson* et al.)

FIGURE 6 – *Low Isles. North-west margin of reef, showing, in foreground, boulder zone (exposed at low tide); in background, the sand cay.*

FIGURE 7 – *Vavau, Tongan Islands. Elevated coral rock, showing its solution by the sea between tidemarks.*

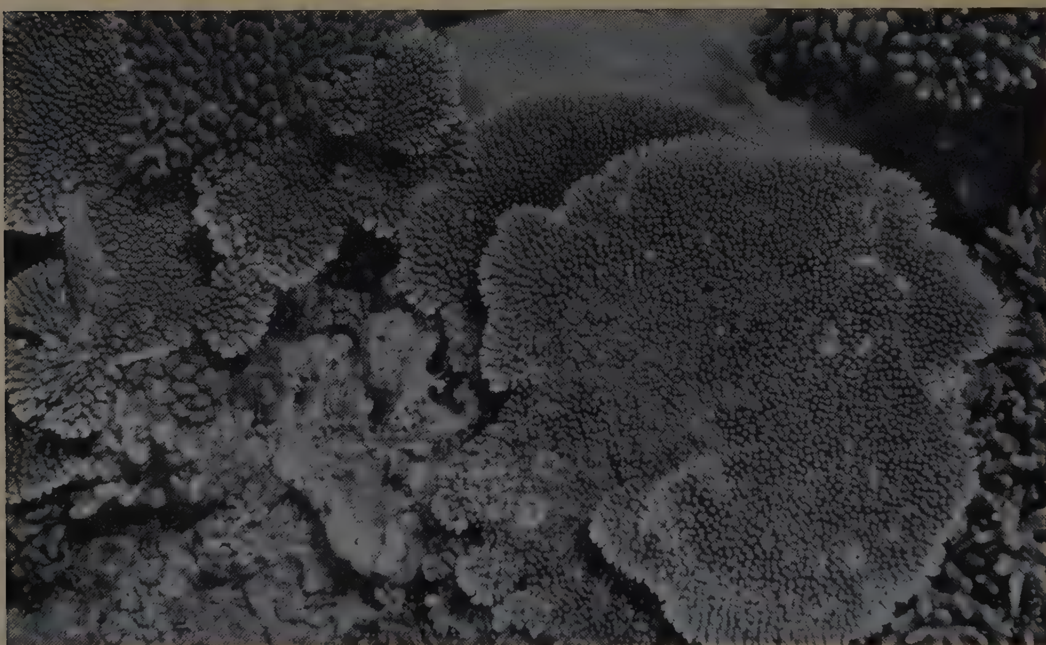
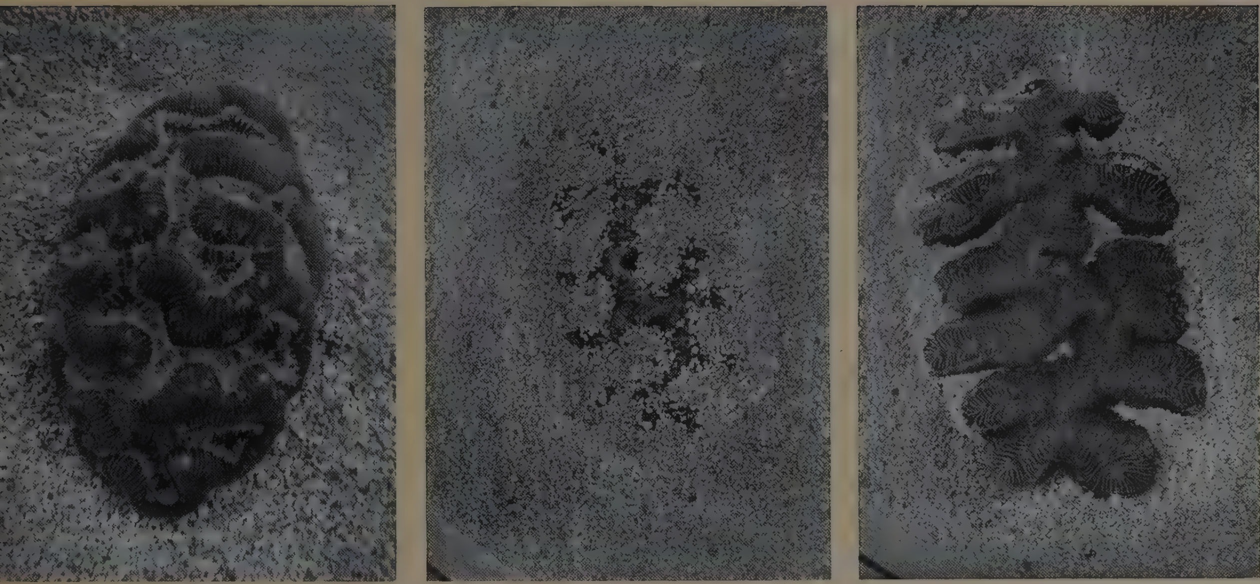


FIGURE 8 – *Summit of a coral pinnacle growing in sheltered water, showing branching coral extending laterally, so producing mushroom form.*



(a) (b) (c)

FIGURE 9 – *Sand-dwelling coral*, Maeandra areolata. (a), *normal appearance on surface of sand;* (b) *and* (c), *stages in emergence after being covered with sand.*

FIGURE 10 – *Mer Island, showing fringing reef* (*see figure* 3), *and reef crest with* Lithothamnion *ridge lying beyond wall of native fish traps.*

FIGURE 11 – *Low Isles. Escarpment of inner rampart with protected moat and mangrove trees in its lee.*

Parallel to the seaward margin, coral fragments accumulate to form a succession of ramparts. Each slopes gently seaward, but has the steep inner escarpment shown in figure 11. Since the original survey of Low Isles in 1928–9 [6], further surveys in 1934 [11] and 1945 [12] have recorded how the ramparts first described have been pushed further over the reef, while a new one has been formed (figure 12). Within the shelter of ramparts, mangrove trees grow, and an extensive swamp covers much of the reef surface.

Where shelter is insufficient for mangroves, the surface of the reef exposed at low tide consists of a flat, with living coral in pools and within a moat formed behind the outer rampart (figure 5). Along the north-west margin, that is on the sheltered side, masses of coral rock form the conspicuous boulder zone shown in figure 6. This consists of the remains of the pinnacles of coral which grow off-shore. Unlike the corals of the exposed face of the reef, which grow under the continuous restraint of powerful seas, these pinnacles grow up in sheltered water. Hence they become unstable, and are broken off and thrown on to the surface of the reef by cyclonic seas that from time to time strike the reefs from northerly directions during the summer. Such tracts of boulders are found only within the cyclone belt, being absent in the East Indies [13] and in the Torres Strait. On the inner side of the crest of outer barrier reefs there is a zone of smaller boulders, but it is uncertain whether these have a similar origin, coming from the lee, or whether they have been carried, like the smaller fragments that form ramparts, over the reef-crest.

Calcareous debris thus collects as shingle rampart, boulder, and sand. The first is maintained by interlocking of fragments, the second by unaided weight, the third by the formation of layers of beach rock around the base of the sand cay. This rock consists of sand particles cemented by calcium carbonate, and it buttresses the sand cay during the summer when it might be washed away by northerly storms. Ramparts, boulders, and sand are all continuously being worn away by exposure to wave action and to the air, and also by dissolution between tidemarks. This dissolution, which does not affect submerged rock, is well

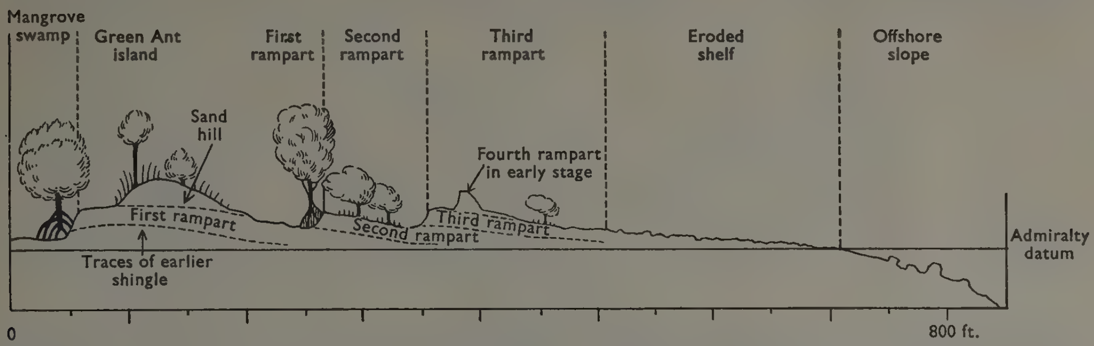


FIGURE 12 – *Low Isles. Diagrammatic section through the rampart system, vertical scale exaggerated 5 times. The fourth rampart has been formed since 1929. (After Fairbridge and Teichert.)*

evidenced around elevated coral islands where, as shown in figure 7, the sea cuts a deep groove. All destruction is at least equalled by new growth of coral.

Similar effects of prevailing weather on the form of reefs have been recorded by Dutch workers in the East Indies [13], and have been observed by the author at the Tortugas Keys in the Gulf of Mexico. They are no less striking on atolls, purely coral formations remote from any land, about which our knowledge has been much extended by recent American work at Bikini and adjacent atolls in the Marshall Islands [14]. The features already noted on barrier and island reefs occur here, though modified owing to the great and now encircling force of the sea. What probably correspond to the two ends of the exposed face of a barrier reef have been bent round to enclose the sheltered lee, the whole forming a great oval. The outer ring of reefs is not everywhere the same. Reefs exposed to seas driven by the north-east trade winds are affected by the immense force of the surf that breaks continuously upon them, and *Lithothamnion* grows thickly (figure 13, *L*). As on Funafuti Atoll [15], and also on the weather side of exposed reefs off the south of Java [13], the *Lithothamnion* extends seaward in a series of spurs with intervening grooves which run inward as deep surge channels. Isolated masses of calcareous algae may grow up, become mushroom-topped, and fuse with one another above, leaving channels below. Openings into these channels form blowholes, through which water is forced high into the air. Details of the formation of these 'room-and-pillar' structures are given in figure 1. The effect of the surge channels is most effectively to dissipate the force of entering seas. Exposed surfaces on more protected reefs within the Great Barrier are serrated.

Marginal reefs on the sheltered western side of Bikini, not exposed to such constantly heavy surf, show evidence of some erosion as a result of summer changes of wind. Embayments, often with contained boulders, are formed by collapse of portions of the reef margin. The reefs that fringe the lagoon are more sheltered on the north-east, and more exposed to seas generated by wind blowing over the lagoon, on the south-west, and they are correspondingly modified in form, though to a much smaller degree than the outer reefs. The lagoon is full of coral knolls which rise from its floor, often almost to the surface, and vary in diameter from tens to hundreds of feet. Within the 24-mile-long lagoon of Eniwetok Atoll, 180,000 soundings revealed over 2000 coral masses [14]. Although often very much larger, they probably correspond to the pinnacles in the lee of barrier and island reefs. Within the shelter of lagoons they can seldom suffer such destruction.

Given an isolated submarine platform, no matter

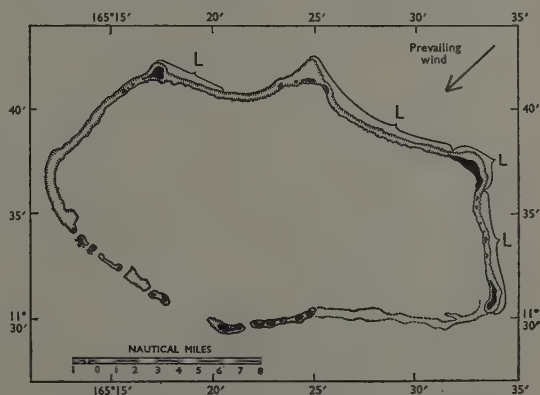


FIGURE 13 – *Bikini Atoll. Outline map, showing arrangement of reefs with islands (shown black) surrounding central lagoon.* L, *fully exposed marginal reefs with* Lithothamnion *ridge. (Modified after Tracey, Ladd, and Hoffmeister.)*

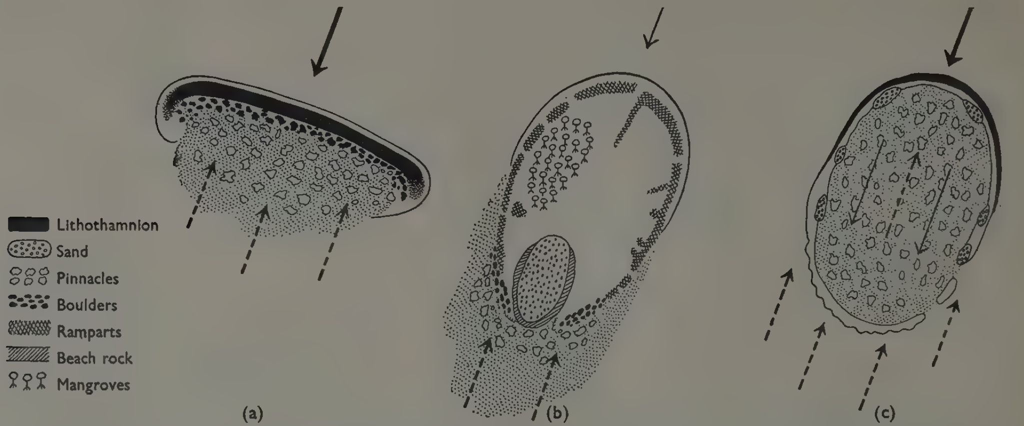


FIGURE 14 – *Diagrams of* (a), *Barrier Reef;* (b), *Island Reef* (*without anchorage, more typical than Low Isles*)*;* (c), *Atoll. Unbroken arrows indicate direction of prevailing winds and, by their thickness, strength of seas which they generate. Reef surfaces on windward side with compact,* Lithothamnion *ridge on* (a) *and* (c) *where seas are very powerful. Broken arrows indicate course of winds and approximate strength* (*very variable*) *of seas causing erosion of the unstable coral growth on the lee side. Shallow water indicated by shading.*

whether subsiding or stationary, within the zone of coral growth the constant movement of the sea will, as outlined for fringing reefs, influence the form of the upward-growing reef. Conditions will be most favourable around the margin of the platform, even the lee of which is bathed with clear water. As marginal coral growth increases, so water movements within will diminish, turbidity will increase, and sediment will be deposited. In this sheltered water certain types of coral will form the characteristic pinnacles. This process can be envisaged as continuing until the marginal reefs, initially no doubt on the weather side, reach the surface. Negative displacement of sea level may then precede the accumulation of sand to form islands, later vegetated. The permanence of these islands, however, may be due to shelter on the side facing the lagoon, over the restricted extent of which no storm, from any direction, can raise seas comparable in force with the oceanic surf outside.

Whatever element of truth there be in these speculations, the fact remains that all reefs show clear evidence of the moulding action of wind and weather, both below and above tidemarks. In figure 14, the most characteristic features of an exposed barrier reef (*a*) are compared with those of a sheltered island reef (*b*), and both with those of an atoll (*c*). In the last, although peripheral exposure is as great as, or greater than, that experienced by a barrier reef, internal shelter is ensured because the reefs encircle a central lagoon.

REFERENCES

[1] Crossland, C. *J. linn. Soc. Lond.* (*Zool.*), **36**, 577, 1928; *Proc. zool. Soc. Lond.*, 717, 1928.
[2] Kawaguti, S. *Palao Trop. Biol. Sta. Studies*, **1**, 199, 209, 1937.
[3] Yonge, C. M. *et al. Sci. Rep. Gt. Barrier Reef Exped.*, **1**, 13, 59, 83, 135, 177, 213, 353, 1930–40.
[4] Verwey, J. *Treubia*, **13**, 169, 1931.
[5] Manton, S. M. *Sci. Rep. Gt. Barrier Reef Exped.*, **3**, 274, 1935.
[6] Stephenson, T. A., Stephenson, A., Tandy, G., and Spender, M. *Ibid.*, **3**, 17, 1931.
Steers. *Ibid.*, **3**, 1, 1930; *Geogr. J.*, **74**, 232, 341, 1929.
Spender. *Ibid.*, **76**, 193, 273, 1930.
[7] Marshall, S. M. and Orr, A. P. *Sci. Rep. Gt. Barrier Reef. Exped.*, **1**, 93, 1931.
[8] Yonge, C. M. *Pap. Tortugas Lab.*, **29**, 185, 1935.
[9] Wood-Jones, F. *Proc. zool. Soc. Lond.*, 518, 1907.
[10] Paradice, W. E. J. *Rep. Gt. Barrier Reef Comm.*, **1**, 52, 1925.
[11] Moorhouse, F. W. *Ibid.*, **4**, 37, 1936.
[12] Fairbridge, R. W. and Teichert, C. *Geogr. J.*, **111**, 67, 1948.
Fairbridge, R. W. *J. Geol.*, **58**, 330, 1950.
[13] Umbgrove, J. H. F. *Bull. geol. Soc. Amer.*, **58**, 729, 1947. (A valuable summary of recent investigations on coral reefs in the East Indies.)
[14] Emery, K. O. *Ibid.*, **59**, 855, 1948.
Tracey, J. I., Ladd, H. S., and Hoffmeister, J. E. *Ibid.*, **59**, 861, 1948.
Ladd, H. S., Tracey, J. I., Wells, J. W., and Emery, K. O. *J. Geol.*, **58**, 410, 1950.
[15] 'The Atoll of Funafuti.' Royal Society, London, 1904.

Antibiotics and microbial antagonism in plant pathology

ERNA GROSSBARD

Although the use of antibiotics in controlling human disease has been one of the most important medical developments of this century, their use in controlling bacterial diseases of plants has hitherto been far less closely studied. There are, however, important possibilities in this direction, on the one hand by direct application of specific antibiotics, and on the other by stimulating, by appropriate manuring, the growth of micro-organisms, naturally present in soil, which produce antibiotics. The outlook seems favourable.

Man's very existence is determined by the activities of the soil microflora. Members of this complex community are among the most important factors in food production, by fixing atmospheric nitrogen, and by acting as agents in the never-ending conversion of plant and animal residues into plant nutrients and, consequently, into human food. Recent researches show that to these beneficial properties may be added the power of soil micro-organisms, such as actinomycetes, bacteria, and fungi, to manufacture potent antibiotics; penicillin, streptomycin, chloromycetin, and aureomycin are well-known examples.

Throughout the whole range of properties which characterize antibiotics we meet with the principle of specificity. Antibiotic action is selective. Only certain groups of micro-organisms are sensitive to one given antibiotic. Strain specificity applies also to the production and concentration of these inhibitive agents. While one strain of a species may be very efficient, another may fail to yield the desired antibiotic. There is specificity as regards the composition of the culture medium and environmental culture conditions. Some factors affecting stability are specific. Some antibiotics are toxic to plant and animal tissue, others may damage plant tissue but not affect that of animals. The mode of action of antibiotics varies considerably; it consists in a subtle interference with certain individual cell reactions of sensitive micro-organisms. This interference more often results in inhibition of growth rather than in a straightforward lethal action. Antibiotics sometimes have the power to lyse (dissolve) microbial tissues. Though themselves manufactured by micro-organisms, antibiotics prevent infection by, and multiplication of, many other micro-organisms responsible for disease in man, animals, and plants.

The diversity in formation and action of antibiotics derives from the variation in their chemical composition. Moulds and actinomycetes are the most prolific sources of antibiotics. While many mould-produced antibiotics are organic acids, such as aspergillic, gladiolic, mycophenolic, or penicillic acids, antibiotics obtained from actinomycetes (such as streptomycin) tend to have basic properties. Many antibiotics manufactured by bacteria are polypeptides, e.g. subtilin. One species may give rise to one or more antibiotics. On the other hand, one and the same compound may be formed by several different organisms.

ANTIBIOTICS FOR THE CONTROL OF PLANT DISEASES

The problem of using antibiotics for plant protection may be approached from two different angles. The materials may be used in a purified and concentrated state as sprays, dusts, and seed or soil disinfectants, or their action may be exploited indirectly on the basis of biological control by microbial antagonism.

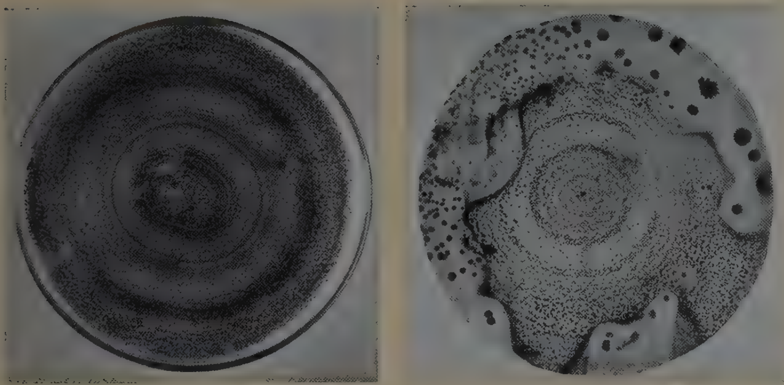
Very little published information is as yet available on the value of antibiotics for plant protection. Much of the work is centred round those materials which have given good results in human therapy. The majority of plant pathogenic bacteria are Gram-negative. As streptomycin is active against both Gram-positive and Gram-negative bacteria, extensive tests were made with this antibiotic, with considerable success. Examples of plant-pathogenic bacteria which are highly sensitive to streptomycin include species of *Xanthomonas* and *Pseudomonas*, causing a variety of leaf-spot diseases of the cucumber, bean, tomato, and stone fruits; *Bacterium carotovorum*, the soft-rot agent of many root crops; *Bacterium tumefaciens*, responsible for

crown gall; and *Corynebacterium michiganense* (exceptional as a Gram-positive plant pathogen). Streptomycin is one of the few antibiotics to have found practical application. It has been used with success as a seed-dressing against bacterial canker of the tomato (*Corynebacterium michiganense*), and as a very effective controller of crown gall. Crown gall is a disease of a variety of plants, especially those which are propagated by grafting. Galls are formed by a process assumed to be somewhat analogous to that of tumour formation in animals. It is for this reason that much research is at present being carried out, especially as regards antibiotic action, on both the causative organism, *Bacterium tumefaciens*, and the tumourous tissue. In field trials penicillin also has been tested. Cotton-wool wrappers soaked in the crude or second-grade preparation of the antibiotic were placed round the aerial galls, or the roots and crown of dormant plants were immersed in the solution, or the material was injected into the stem. It is claimed that not only was the disease arrested but that the tumours already formed were destroyed and eventually dried up (figures 5–7). Streptomycin was more efficient in action than penicillin. There is some disagreement as regards the effect of the antibiotics on tumour tissue. Workers who have used the purest preparations of the antibiotics available, studying the problem in tissue cultures, did not observe regression of tumour tissue. Such disagreement of results is not infrequent, and may be explained by the fact that materials were not standardized. This probably applies to the somewhat contradictory reports on actidione, the only antifungal agent known to be produced by *Streptomyces griseus*. While some plant pathologists claim that they have obtained a very good protection of beans from mildew (*Erysiphe polygoni*) by spraying the plants with actidione at concentrations of 5 parts per million, without any injury to the plants, others report serious phytocidal effects.

Many human diseases are of bacterial origin, and the antibiotics used in human therapy are consequently antibacterial. The great majority of plant diseases, however, are caused by fungi, and it is therefore essential that plant pathologists should isolate materials which are primarily antifungal. Investigations on these lines have led to the preparation of a variety of antifungal substances. Examples are gliotoxin and viridin, both isolated from the green mould *Trichoderma*; gladiolic acid from *Penicillium gladioli*, a parasite of gladioli corms; griseofulvin, frequentin, and a red pigment from various soil *Penicillia*; musarin from an actinomycete inhibiting *Fusarium oxysporum cubense*; and antimycin from an unidentified species of *Streptomyces*. Gliotoxin was tested as a seed-dressing, but although it inhibited several pathogens of cereals the concentrations required and the costs of production are too high to render it more suitable as a seed-dressing than the organo-mercurials used at present. The results of experiments recently carried out in Britain with griseofulvin are very encouraging. It has been convincingly demonstrated that this antibiotic has the properties of a systemic fungicide. It was taken up by the roots and translocated throughout the plant, protecting it to a considerable degree against infection. Lettuces were grown in nutrient solutions containing griseofulvin, and tomatoes were raised in sand cultures watered at intervals with this antibiotic; the lettuces were inoculated with *Botrytis cinerea* and the tomatoes with *Alternaria solani*. The treatment with griseofulvin considerably reduced disease incidence in both crops. An immunity of 74 per cent. was recorded for the tomato plants. Though still in the experimental stage this work is of great importance, because it opens up new roads in the field of chemotherapy in plants. Systemic fungicides are known, but their number and range of activity is small. Antimycin, isolated in the United States and tested extensively in greenhouse trials, may be regarded as a promising antibiotic fungicide. It inhibits germination and growth of *Venturia inaequalis* (a fungus causing scab on apples and pears) and a variety of other plant pathogens. It has the merit of not causing any injury to the plant. When artificial rain was applied, antimycin retained its activity for a considerable time. It can be used together with the routine sprays of insecticides without becoming inactive. These examples serve to show that in the not too distant future antibiotics may become a useful source of new types of fungicides. One of the greatest obstacles to be overcome is the high cost of production of these new materials. It has, however, been possible to synthesize chloromycetin on a commercial scale, and it is hoped that other antibiotics may be produced in this sometimes more economical manner. For plant protection, the cheaper second-grade or crude product can frequently be used with good results.

MICROBIAL ANTAGONISM

There is a mode of disease-control in which the principle of antibiotic action may be utilized without involving great expense.



(a) (b)

FIGURE 1 – *Example of competition between* Colletotrichum atramentarium, *a tomato parasite, and two other micro-organisms. In* (a) *growth of* C. atramentarium *is unaffected, but in* (b) *an abnormal colony has resulted.*

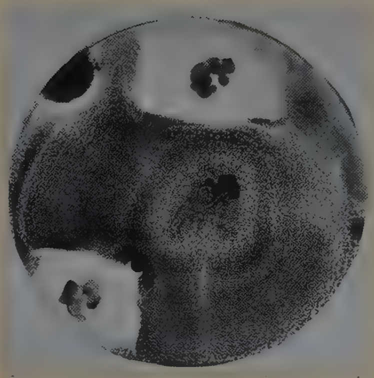


FIGURE 2 – *This culture of* C. atramentarium *has been inoculated with four other micro-organisms, but only one, an actinomycete inoculated at two opposite points, has proved antagonistic.*

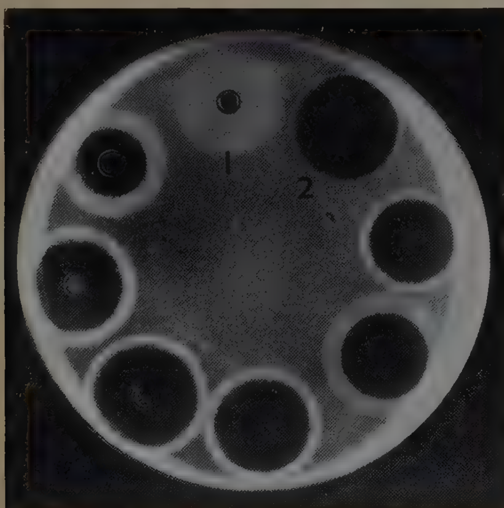


FIGURE 3 – *Assays, by the cylinder plate method developed for penicillin, of fluids from soils inoculated with* P. patulum, *and manured with various sources of carbohydrate. The test organism is a soil bacillus.* (1) *is fluid from uninoculated soil;* (2) *contains a solution of expansine* (*patulin*).

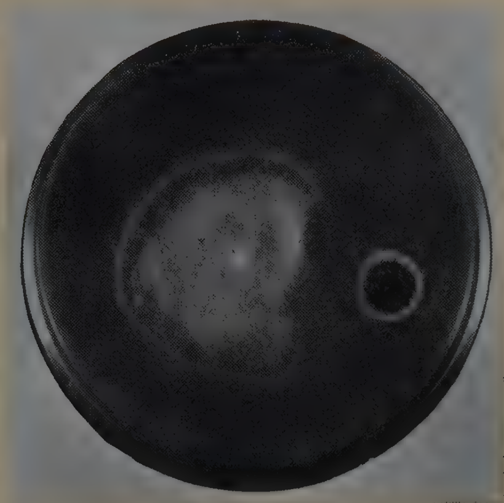


FIGURE 4 – *Disintegration of hyphae of a fungus causing 'damping-off' by an antagonistic micro-organism introduced after the fungus had established itself.*

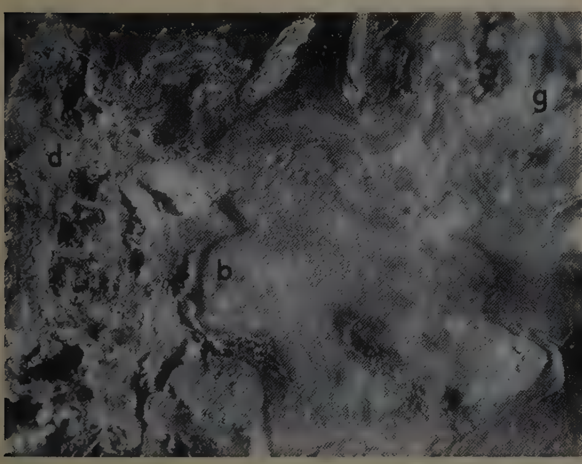


FIGURE 5 – *Section of artificial gall on* Bryophyllum pinnatum *after penicillin treatment.* (d) *Dead gall tissue;* (b) *healthy tissue;* (g) *untreated, active gall tissue.* (*By courtesy of Prof. J. G. Brown.*)

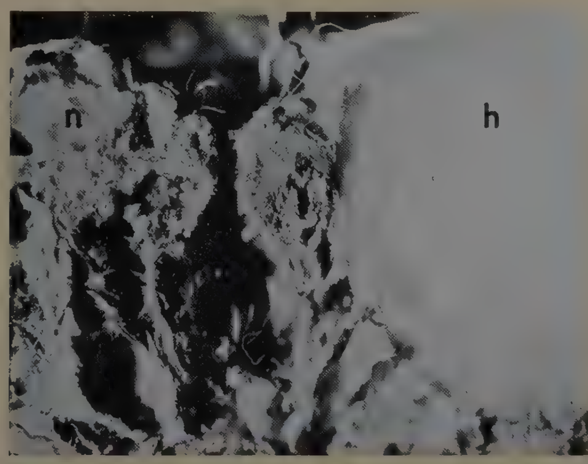
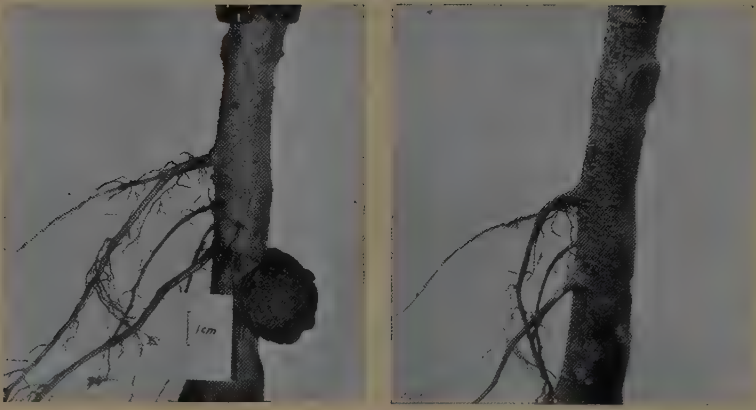


FIGURE 6 – *Transverse section of artificial gall after streptomycin treatment. Gall tissue at* (n) *is dead and disintegrating, but untreated tissue* (h) *is unaffected.* (*By courtesy of Prof. J. G. Brown.*)



(a) (b)

FIGURE 7 – *Effect of treating crown gall on greengage with penicillin:* (a) *before treatment,* (b) *eight weeks later.*

(*By courtesy of Prof. J. G. Brown.*)

FIGURE 8 – *Photograph of* Aspergillus clavatus. *This species forms expansine (patulin) on standard laboratory media; when grown on organic manures or on soil it also produces an antibiotic.*

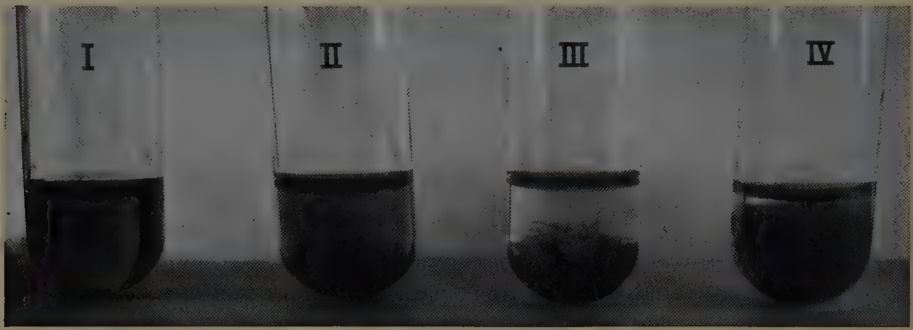


FIGURE 9 – *Inhibition of the parasite* Phytophthora *by extracts of soil inoculated with moulds producing antibiotics. The soils were inoculated with (I)* P. patulum, *(II)* A. terreus, *and (III) an unidentified mould. (IV) is a control.*

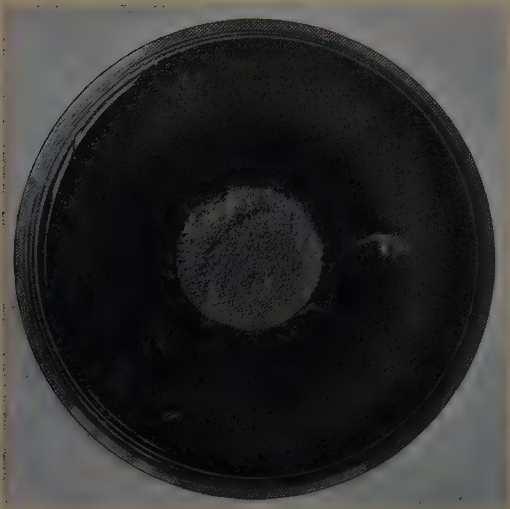


FIGURE 10 – *Inhibition of growth of* Bacterium carotovorum, *a soft-rot organism, by a disc of* A. clavatus *inserted in agar inoculated with the bacteria. The active substance produced is expansine (patulin).*

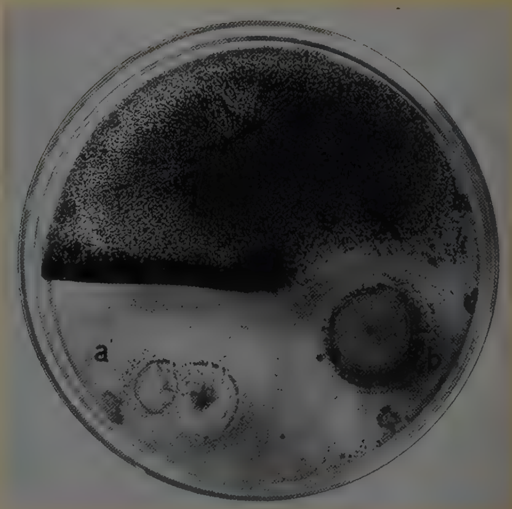


FIGURE 11 – *Inhibition of* Colletotrichum atramentarium *by* (a) *a strongly antagonistic* Penicillium *and* (b) *a weakly antagonistic* Penicillium.

(*All photographs, except figures 5–7, by J. E. Morton and H. Tooley*).

In mixed cultures, one or a group of micro-organisms may be inhibited by the activities of another; this is termed microbial antagonism. An interesting application of it to disease-control has been investigated in Britain. Lettuces are frequently attacked by the grey mould *Botrytis cinerea*, and many micro-organisms are antagonistic to *Botrytis*. It has been possible to colonize moribund tissues of lettuces, usually found on the lower leaves, with antagonistic organisms. Subsequent infection by *Botrytis* of plants cultivated in frames was considerably reduced. This kind of method of preventive control seems very promising.

MICROBIAL ANTAGONISM AND ORGANIC MANURING

Attempts to control plant diseases by the mechanism of microbial antagonism refer chiefly to root diseases. It has been found empirically that many soil-borne parasites are suppressed by heavily manuring the infected soils with organic matter. The classical work carried out in Britain was the control of potato scab by incorporating large quantities of green manures with the soil. In Arizona and other cotton-growing areas, the serious cotton root-rot disease (*Phymatotrichum omnivorum*) was successfully controlled by putting large quantities of hay and other manures into deep furrows. Canadian workers were able to eradicate strawberry root-rot and scab of potatoes by ploughing in a crop of soy-beans. The basis of these control measures is a modification of the soil microflora, and a stimulation of a mode of microbial activity antagonistic to certain parasites. By the incorporation of plant and animal residues, new types of micro-organism are introduced which are chiefly saprophytes, living on dead matter only. They may have been present already in a particular soil, especially as ungerminated spores. The additional food-supply encourages their development and antagonistic activity.

Canadian scientists, working on the control of strawberry root-rot and potato scab, have applied several types of manure, such as red clover, rye grass, and soy-beans. Though the first two effected a shift in the microbial balance, only soy-beans controlled the disease. A similar result was obtained when glucose or similarly rich sources of carbohydrate were applied. It was concluded, therefore, that the type of decomposition, in this case the carbohydrate breakdown, is an important factor. The parasite *Ophiobolus graminis*, responsible for a disease of cereals aptly named 'take all,' can be eradicated by the use of manures of a high carbon but low nitrogen content. It is thus not sufficient to employ merely organic matter: the choice of an appropriate material is essential.

In the mechanisms of microbial antagonism many factors are concerned, such as competition for food; an excess of carbon dioxide; and the formation of toxins. The question now arises—are such toxins antibiotic substances, and is there a correlation between organic manuring and the formation of antibiotics in the soil ?

ANTIBIOTICS IN THE SOIL

Many of the micro-organisms which produce antibiotics on standard laboratory media were isolated from the soil. While the soil can be regarded as their natural habitat, it does not necessarily follow that the antibiotics associated with them will be formed on so poor a medium as is furnished by soil alone. It has been suggested that manuring might supply additional nutrients to induce antibiotic formation directly in the soil. Experiments in Britain have shown that certain saprophytes which are known to produce antibiotics on laboratory media will form an inhibitive agent when grown on materials, frequently employed in agriculture as manures, such as straw, timothy, and bracken, which have been sterilized. It can be argued that organic manuring not only modifies the microflora but stimulates antibiotic formation in the soil. This hypothesis is supported by results of other experiments initiated in Britain. Antibiotic activity against plant pathogens such as *Phytophthora parasitica* (damping off), *Thialviopsis basicola* (tobacco root-rot), and *Bacterium carotovorum* was demonstrated in soil centrifugates prepared from either partially or completely sterilized soils inoculated with one of several fungi which produce antibiotics on standard laboratory media. This effect was, however, dependent on the presence of an additional carbohydrate source in the soil. This suggested that apart from carbohydrates, which can be supplied by manuring, the soil can be regarded as a suitable medium for antibiotic production, at least by certain fungi. The part antibiotics can play in microbial antagonism is also dependent on the length of time antibiotics retain their activity in the soil. Though it has been shown that some antibiotics, especially those of a basic nature, are adsorbed by colloids, workers in Britain demonstrated that some antibiotics persisted in the soil for a considerable time, and that activity was retained longest in soils of the same type as that from which the fungi were originally isolated. Although no claim has yet

been made that a material was extracted from soils which could be identified chemically as one of the known antibiotics, there is strong evidence to suggest that antibiotics are present or may be established in certain soils. It is also significant that requirements essential for the control of certain soil-borne pathogens are similar to those necessary for antibiotic production in the soil under controlled conditions—namely, materials high in carbon and low in nitrogen content. Furthermore, it has been demonstrated by very sensitive extraction methods that extracts from natural soils which were not inoculated with any specific organisms, but treated with glucose or a similar carbohydrate, displayed antibiotic activity.

Practical applications of these findings have been attempted. Soils partially sterilized, according to practices established in nurseries, were inoculated with an antagonist of the damping-off parasite *Phytophthora parasitica*, and these soils were manured with various sources of carbohydrate in an attempt to control damping-off of tomato seedlings. After incubation the parasite was introduced and seeds were sown. During the period of treatment the soil became rapidly recontaminated and could be no longer regarded as partially sterilized. The results obtained showed considerable variations, an experience frequently observed in work on microbial antagonism. The spread of the disease from a centre of infection was considerably reduced when sugar-beet pulp was employed as a manure. While the addition of straw, or straw plus glucose, frequently gave similar results, these treatments often stimulated rather than controlled damping-off. Experiments were carried out with *Rhizoctonia solani* on lettuces. In sterile soil, the incidence of disease was considerably reduced, but in the field the treatment was ineffective.

Many reports are current that certain pathogens have been suppressed by the inoculation of soils with antagonistic cultures without the addition of any nutrients. This work was initiated by the control of *Rhizoctonia solani*, causing damping-off of citrus seedlings, by inoculation with *Trichoderma spp.*, but in this case a change of soil conditions was carried out by acidification. 'Take all' was controlled by adding antagonists to the soil. Similar reports come from Russia as regards cereal diseases; from India in relation to cotton wilt; and from France in respect of the control of wilt of melons and the sclerotinia disease of sunflower.

The outstanding feature of these results was that control was very effective in sterilized soil, but less effective or not significant in non-sterile soil. As regards natural, unsterile soil, reduction of disease and increase in growth-rate is reported from the West Indies, where fields infected with Panama disease received bulk inoculation of antagonistic actinomycetes. This indicates that under certain conditions the soil, as such, without further adjustments, supports growth of antagonists and stimulates antagonistic activity. However, in general it appears that satisfactory results in controlling plant pathogens are more likely to be obtained by manuring the soil in addition to the introduction of antagonistic organisms, especially in unsterile soil.

There is an unwieldy mass of data available on the above mode of control. Comparisons are difficult, as the materials and strains of pathogens and their respective antagonists were not standardized. Failure and success have been reported. The difficulties with which pathologists are faced here are very similar to those which had to be solved before the introduction into certain soils of efficient strains of nodule bacteria on legumes was possible. Land on which it was formerly impossible to grow leguminous crops successfully, because of the absence of an efficient strain of the nodule bacterium which fixes atmospheric nitrogen, now supports a good crop when the seeds are dressed with a specific strain of the nodule bacterium.

BIBLIOGRAPHY

ARK, P. A. 'Streptomycin,' edited by S. A. Waksman. P. 107. Baillière, Tindall and Cox. London. 1949.
BROWN, J. G. and BOYLE, ALICE M. *Phytopathology*, **35**, 521, 1945.
Idem. Proc. 7th Int. Bot. Congr., 1950 (in press).
BRIAN, P. W., *et al. Ann. appl. Biol.*, **32**, 214, 1945.
Idem. Nature, **167**, 347, 1951.
GARRETT, S. D. *Ann. appl. Biol.*, **25**, 742, 1938.
GROSSBARD, ERNA. *Nature*, **161**, 614, 1948.
Idem. Proc. 7th Int. Bot. Congr., 1950 (in press).
Idem. Rep. Exp. Res. Sta. Cheshunt, 1946–1949.
LEBEN, C. and KEITH, G. W. *Phytopathology*, **39**, 529, 1949.
NANDI, P. N. and JACOBS, S. E. Ph.D. Thesis, 'The Influence of Antibiotics on Micro-organisms in Soil.' University of London. 1948.
ROUATT, J. W. and ATKINSON, R. G. *Canad. J. Res.* (*C*), **28**, 140, 1950.
WOOD, R. K. S. *Ann. appl. Biol.*, **38**, 271, 1951.

REVIEWS

BRIAN, P. W. *Chem. and Ind.*, **68**, 391, 1949.
DARPOUX, H. and FAIVRE-AMIOT, A. *Rev. Path. vég.*, **29**, 102, 1950.
GARRETT, S. D. *Biol. Rev.*, **25**, 220, 1950.
LOCHHEAD, A. G. and LANDERKIN, G. B. *Plant and Soil*, **1**, 271, 1949.

Water in the architecture of plants

T. A. BENNET-CLARK

Water is of great importance as a structural material in plants. The maintenance by plants of an excess hydrostatic pressure—which keeps them rigid much as air keeps an inflated tyre rigid—poses an important question, for there must exist a mechanism by which flow of solute is maintained against the concentration gradient. In consequence energy is used up, and it must be concluded that plants work continuously merely to keep themselves erect.

Architecture may involve study of styles and construction. It must also include study of the properties of building materials, and it is this latter aspect of plant architecture with which we are here concerned.

The water in a plant may be compared in its relevant structural importance with the compressed air in a pneumatic tyre. The structural water is indeed compressed to surprisingly high pressures inside the cells of most plants. The analogy with pneumatic tyres is rather close, and in both tyres and plant cells the rigidity of the structure is determined jointly by the elasticity of the cover and the excess pressure of the gaseous or fluid contents.

Recognition of the structure and mechanism of this building unit of the plant has been achieved very slowly. Robert Hooke observed the subdivision of the plant body into compartments which he termed cells, but it was not until Moldenhawer (in the first decade of the nineteenth century) devised the technique of maceration that the structure of a mass of similar cells became clear. These groups of cells had been called tissues by Nehemiah Grew in his great work on plant anatomy, and that term, in current use in the biological sciences today, enshrines the fact that he did not recognize the separateness of the walls of individual cells but thought that the fabric of cells was a woven structure like lace.

The recognition of the protoplast or primordial utricle as a lining to the cell wall marked the next advance, but it was not until much later in the century that clear conceptions emerged regarding the status of the water, protoplast, and wall of a typical plant cell.

The classic work of the great plant physiologists Dutrochet, Pfeffer, and de Vries not only provided the student of the living plant with much of the information that he required, but has had immense repercussions in the field of pure chemistry; it represents probably the most important 'reciprocal lend-lease' between botanists and chemists. Dutrochet first observed the phenomenon, and coined the term osmosis. Pfeffer's determinations of osmotic pressure at different temperatures and concentrations provided the data from which van't Hoff developed the theory of dilute solutions, and de Vries's recognition of the abnormally large osmotic pressures of electrolytes helped to pave the way, in the hands of Arrhenius, for the concept of ionic dissociation.

This is the historical reason why many text-books of physics and of chemistry contain diagrammatic pictures of a plant cell. A cell or tissue of cells which is relatively rigid is described as turgid; those which have been plasmolysed are flaccid. Plasmolysis is due to water passing from the central cavity or vacuole into the external medium; this is not associated with passage outwards of solutes from the vacuole. These appear to be retained, and the protoplast, or more precisely the vacuolar membrane, has therefore been regarded as a semi-permeable membrane.

There has been little emphasis on the remarkable character of the phenomenon of plasmolysis. It implies the absence of adhesion of protoplast to cell wall, or, if the external layer of the protoplast is adherent, it would seem that some internal layer concentric with it is readily sheared. This, however, seems unlikely, for the protoplast shows little or no sign of injury as a result of being prised away from the wall.

One must clearly attempt to estimate the magnitudes of these hydrostatic pressures of contents of plant cells if one is to discover anything about the methods by which they are produced and maintained.

Two types of method can be used to obtain estimates of the excess hydrostatic pressure of the contents of plant cells. The procedures are illustrated diagrammatically in figure 1. The

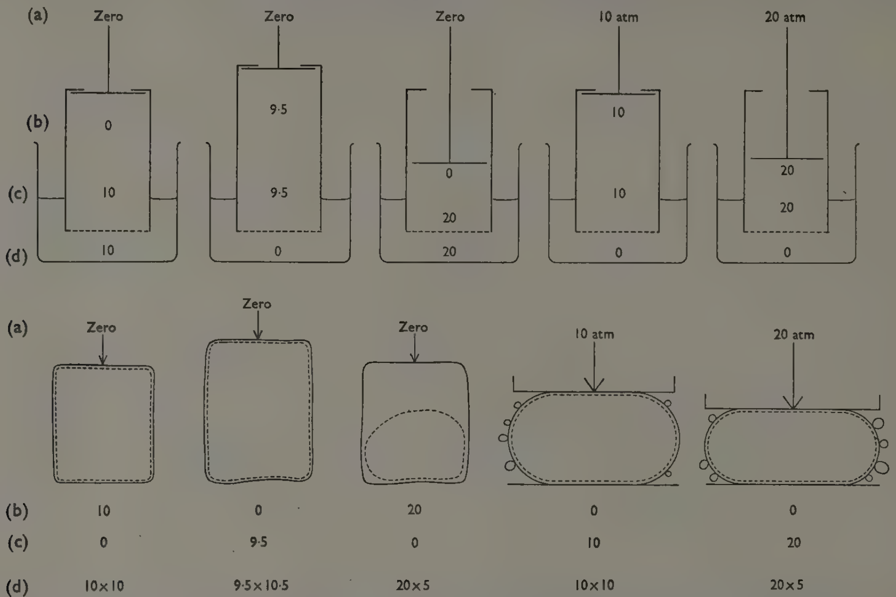


FIGURE 1 – (*Upper part*) *Cylinders with semipermeable end-walls, containing solutions of osmotic pressure indicated, immersed in other solutions. Figures indicate* (a) *excess pressure above atmospheric applied to the pistons,* (b) *excess internal hydrostatic pressure,* (c) *internal osmotic pressure, and* (d) *external osmotic pressure.* (*Lower part*) *A plant cell treated in the same manner as the cylinder represented immediately above. Figures indicate* (a) *excess applied pressure,* (b) *external osmotic pressure,* (c) *wall pressure, which equals internal excess hydrostatic pressure,* (d) *internal osmotic pressure* × *vacuolar volume. Note that compression causes exudation of drops of water pressed out of the vacuole.*

lower diagrams represent a living cell immersed in solutions of 10, zero, and 20 atm osmotic pressure and subjected to mechanically applied pressures of 10 and 20 atm respectively. This cell is represented as having expanded about 5 per cent. in volume when the wall is stretched by the maximum hydrostatic pressure (9·5 atm) which the cell contents can generate on immersion in pure water. The upper diagrams represent the behaviour of a cylinder having a semipermeable end-wall, so constructed that it elongates somewhat when an excess internal pressure forces the piston against the stop-ring at the top of the cylinder. The unstressed cylinder is supposed to be completely filled with a solution of 10 atm osmotic pressure (the solute being one which does not pass through the semipermeable membrane).

The cylinder is shown immersed in solutions of osmotic pressure 10 atm, zero, and 20 atm, and with excess applied pressures to the piston of zero, 10, and 20 atm. The curve in figure 2 shows the relation between excess applied pressures as abscissae, and percentage of the total water pressed out as ordinates. The cylinder and cell wall are represented as stretching so that the volume is about 5 per cent. above their unstressed volume when the internal excess hydrostatic pressure equals 9·5 atm. The graphical record thus shows that about 5 per cent. of the internal water is pressed out by an applied pressure of 10 atm. Larger applied pressures than this push the piston down into the cylinder, pressing out the volumes of water indicated graphically.

If one assumes that PV is a constant, one can obtain the initial hydrostatic pressure of the cylinder or cell contents from graphical records of the type shown. Extrapolation of the curve *AB* to the zero ordinate gives the hydrostatic pressure when the piston is about to be pushed in from the stop-ring. The ordinate of *B* is an estimate of the extensibility of the cylinder. If the extensibility of the cylinder or the cell is very small, in other words if the points *B* and *C* nearly coincide, the abscissa *DC* is a direct measure of the hydrostatic pressure of the contents.

Figure 3 shows the relation between the volume expressed and the applied pressure in the case of beech leaves, where in this experiment *B* and *C* were nearly coincident. This coincidence is not invariable, but it is not uncommon in thin leaves. One can also determine the external osmotic pressure

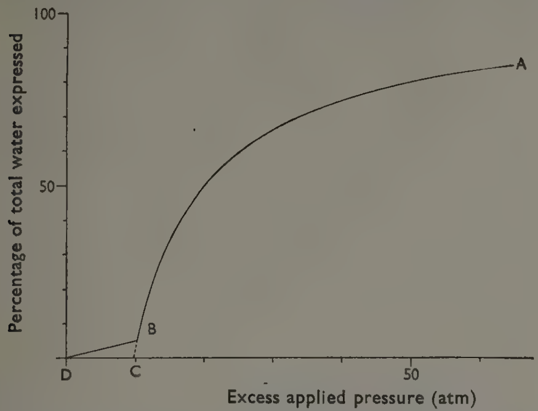


FIGURE 2 – *Ordinates show percentage of total water pressed out of cylinders or cells such as those of figure 1 by the excess applied pressures, shown as abscissae.*

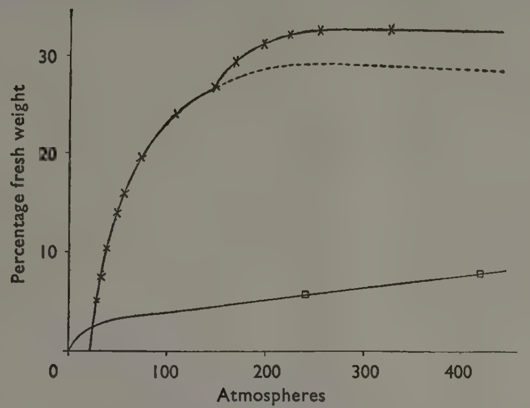


FIGURE 3 – *Volumes of juice expressed by small pressure increments from leaves of* Fagus sylvatica; *living leaves*—x—; *killed residue from fully pressed living leaves* —□—.
(*By courtesy of* The New Phytologist.)

required to cause the protoplast just to contract away from the wall. This osmotic pressure should theoretically be equal to the pressure indicated by the abscissa of *C* in figure 2. Within the limits of the considerable experimental errors this was found to be so [1].

One has, then, some confidence in the determinations of the hydrostatic pressure of cell contents in a number of cases, whether the direct mechanical pressure method or the plasmolytic method has been used. The plasmolytic method had been used as early as 1880 by de Vries, but recent work has shown the existence of a remarkably large difference between the estimate of internal hydrostatic pressure based on the plasmolytic method and the actual osmotic pressure of the expressed juice, and, as the latter has most usually been found to be considerably less, the true significance of the plasmolytic estimate is naturally called in question.

The agreement between the plasmolytically and mechanically determined hydrostatic pressure is therefore significant. It had been thought that the hydrostatic pressure was developed in cells solely as a consequence of the difference in activity of water inside and out, as in the model cylinders of figure 1. Though this view is still held by many workers, it is not by any means certain that it is completely correct.

A feature of the high hydrostatic pressures in plant cells, that seems to be little emphasized in the earlier researches, is that it implies that the living protoplasts do work in pumping material into the cell to produce the excess pressure in the first instance, and to maintain it against leakage afterwards.

The real problem of the architecture of plants is how this work is done, and what fraction of the energy made available in respiration is used in this manner.

One might describe as the simple osmotic view the hypothesis that the sole mechanism consists of the accumulation of electrolytes and non-electrolytes inside the vacuoles of cells against a concentration gradient. That this occurs is amply supported by many investigators. The most striking instances are noted in the case of electrolytes, where penetration inwards is observed even when the internal concentration of the solute is as much as 400 times the external.

This clearly would cause a lower activity of water inside the vacuole than outside, were it not that some simultaneous inflow of water causes a rise of hydrostatic pressure. The system envisaged is really a dynamic equilibrium in which any leakage of solute from the internal solution is made good by active secretion, and in which an excess hydrostatic pressure is built up equalling the osmotic pressure of the internal solution, thus causing the activity or chemical potential of water to be equal on both sides of the cell membrane.

The important point to elucidate is the mechanism of solute uptake or secretion against a concentration gradient. In recent years, a number of significant findings has been made. The uptake has been shown to be closely linked with aerobic respiration (Steward, Hoagland, and others). Uptake of salts was shown to be associated with an increase in rate of respiration above what has been termed the ground-respiration; this extra salt-respiration is cyanide-sensitive, and the suggestion has been made that it is linked with a cytochrome system.

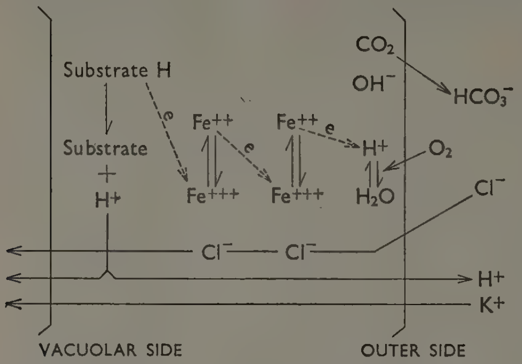


FIGURE 4 – *Scheme of electron transfer by* Fe^{++} : Fe^{+++} *system (possibly cytochrome) coupled with ion exchanges (somewhat modified from Robertson and Wilkins* [6], *Crane* et al. [2], *and Lundegårdh* [4]).

Still more recently, the very important finding has been made by Robertson and his co-workers that a stoichiometric relation exists between the salt-respiration and salt-uptake, when the external concentration of salts is high enough not to be limiting the rate of uptake. Under these conditions, the uptake of 4 anions is associated with consumption of 1 molecule of oxygen.

The importance of this finding in relation to recent work on the mechanism of secretion of hydrochloric acid by gastric mucosa, and to Lundegårdh's suggestions regarding the mechanism of salt-uptake, has been the subject of several recent papers.

A result of fundamental importance is the finding by Rehm [5]; Crane, Davies, and Longmuir [2]; and others, that the ionic composition of the phases on the two sides of certain isolated secretory membranes, such as gastric mucosa of the frog, had little effect on the potential difference across it. Korr [3] had already pointed out that the oxidation-reduction potential in the system:

$$\text{Hg HgCl} \left| \text{KCl} \right| \begin{matrix} Fe^{++}> \\ Fe^{+++} \end{matrix} \left| \text{Metal} \right| \begin{matrix} Fe^{++}< \\ Fe^{+++} \end{matrix} \left| \text{KCl} \right| \text{HgCl Hg}$$
$$\xrightarrow[e]{}$$

can be measured if a metallic (electron-transferring) membrane is placed between the two redox systems as shown.

Lundegårdh had suggested that an electron-transferring array consisting of an oxidizing enzyme-complex could act as a mechanism of anion uptake, though it was hardly possible to get direct evidence in favour of his view. Crane *et al.* [2], and Robertson and Wilkins [6], have elaborated this view and suggest a scheme such as is shown in figure 4.

A point of some interest in the behaviour of gastric mucosa is that the onset of secretion is associated with decrease in potential difference between secretory and nutrient side of the membrane. The independence of the membrane potential difference from *p*H and other ion-concentration differences suggests that this potential difference is caused by oxidation-reduction potential differences on the two sides of the membrane, and that an electron-transfer mechanism exists—that the membrane is in fact a type of semi-conductor.

In a normal-sized parenchyma cell of a plant, the high internal hydrostatic pressure makes the problem of determining potential differences between vacuole and external medium one of great difficulty. It is, however, apparently the case that tissues immersed in a medium such as distilled water, and free from external supply of ions, show a rather marked discrepancy between plasmolytically and cryoscopically determined osmotic pressure, which suggests that active secretion of water is taking place. This condition of absence of salt-secretion might, from analogy with behaviour of mucosa, be expected to bring about a greater potential difference across the cell membrane, and thus to promote increased electrosmotic flow of water inwards or maintenance of an excess 'active pressure' by electrosmosis.

Though there is still much uncertainty as to whether water is actively secreted, perhaps electro-osmotically as suggested above, there is no doubt that the high excess hydrostatic pressures of plant cells are generated and then maintained by active secretory processes, either of solutes or, less certainly, of water.

Interference with the normal processes of respiration are at once accompanied by outward diffusion of solutes and reduction of the internal excess hydrostatic pressure on which the mechanical strength and rigidity of the tissues depend.

REFERENCES

[1] BENNET-CLARK, T. A. and BEXON, D. *New Phytol.*, **39**, 337, 1940.
[2] CRANE, E. E., DAVIES, R. E., and LONGMUIR, N. M. *Biochem. J.*, **43**, 321, 336, 1948.
[3] KORR, I. M. *Cold Spr. Harb. Sym. Quan. Biol.*, **7**, 74, 1939.
[4] LUNDEGÅRDH, H. *Ark. Bot.*, **32**, 1, 1945.
[5] REHM, W. S. *Amer. J. Physiol.*, **147**, 69, 1946.
[6] ROBERTSON, R. N. and WILKINS, M. J. *Aust. J. Sci. Res.*, B., **1**, 77, 1948.

Underground gasification of coal

H. ROXBEE COX

Gas produced by the underground gasification of coal is unlikely to be suitable for domestic purposes owing to its comparatively low calorific value. It could, however, be used for heating and for power generation. Underground gasification offers the advantage of a means of exploiting coal seams which are too poor or too narrow to be worth mining in the ordinary way. It has yet to be proved whether or not the process is economically attractive, but its possibilities are such that it is being investigated in a number of countries, including Britain.

There is an extensive literature [1] on the underground gasification of coal, the greater part emanating from Russia, where considerable progress seems to have been made. Elsewhere in the world work has been begun, and results achieved in that part of it done outside Britain have been reported [2–8]. While, therefore, a brief reference will be made to the work done in other countries, the main purpose of this article is to give a brief account of what has recently been done in England. This work will be fully dealt with later elsewhere, in papers written by the men who have been in charge of it on the spot. To these detailed papers the present article may be regarded as a brief introduction by one whose responsibility was to initiate the present series of experiments.

Reduced to its simplest terms, underground gasification means heating coal while it is still in the coal seam, in such a way that gas is produced which can be brought to the surface and used there. This can be done in a variety of ways, and the method to be adopted on a particular site must always be largely dictated by the local conditions. For the purpose of illustration it is perhaps simplest to consider first the elementary system shown in figure 1. This diagram indicates that two holes have been drilled vertically downwards from the surface until they reach a seam of coal, and that another hole has been made more or less horizontally in the coal seam joining the bottoms of the two vertical holes. If a fire is started in the coal, and air is pumped down one of the vertical shafts, then so long as the fire is burning we may expect to find hot gas coming up the other vertical bore-hole.

In effect, what we seek to do is to start in a small part of the coal a small fire, the gases from which will be sufficiently hot to maintain continuous gasification of the rest of the coal, but will not contain sufficient oxygen to permit its complete combustion. It is clear, therefore, that the air supply must be correctly controlled if the gas coming to the surface is to have a calorific value as well as sensible heat. If too much air is supplied, the coal will be completely burned underground, and though we should then get hot flue gases, the heat of which could be turned to good account, they would in general be less convenient to use than a gas which can be burned.

A system such as that in figure 1 could be produced by underground working, but other ways

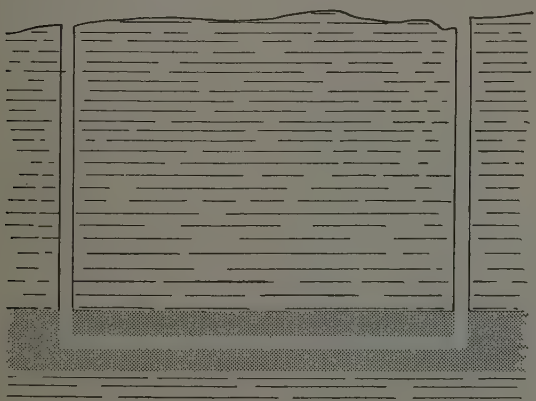


FIGURE 1

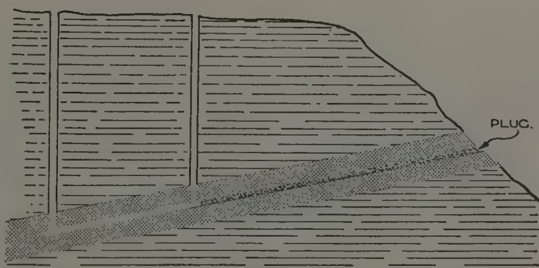


FIGURE 2

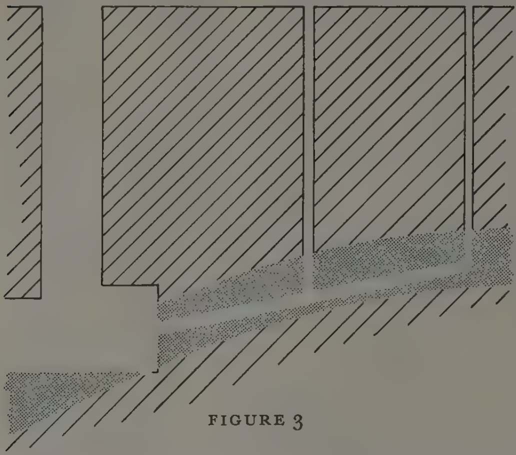


FIGURE 3

of doing it are sometimes possible. Where the lie of the land and the run of the coal seams permit, it is possible to drill the verticals from high ground, and to put in the horizontal by drilling from an external surface, as indicated in figure 2. A variation of this arrangement, when there is coal available in the vicinity of a disused mine, is to make a horizontal drilling from an abandoned working, as indicated in figure 3.

It is not difficult to imagine that in a large-scale undertaking there would be a number of systems, of the type shown in figure 1, with their upcasts connected to form a supply of power gas to electrical generating plant. I use the words 'power gas' advisedly, because it is very improbable that the gas produced would have a calorific value high enough to permit it to be used for domestic purposes.

Behind the foregoing simple descriptions there is the tacit assumption that the coal seam to be gasified is lying more or less horizontally. Frequently, however, coal seams dip steeply, and, when they do, a rather different system can be used if desired. Figure 4 shows a portion of a steeply dipping seam in which two shafts lying entirely in the coal have been mined from the surface. The bottoms of these shafts, as before, are joined by a more or less horizontal mined shaft. If gasification is imagined to have started in the shafts, it is easy to visualize that the whole of the coal bounded by the shafts—indicated by the full lines in the figure—will ultimately be gasified. An even simpler system, which could be made entirely by drilling, would be obtained if the two shafts from the surface were so directed as to intersect.

The work now in progress on a modest scale in Britain is part of a programme of scientific research and experiment designed to exploit to the full the indigenous fuel resources of the country. It is imperative to use coal resources as economically and as completely as possible. This does not mean only that we must burn coal in the most efficient way. It means also that we must try to use sources of energy which have not hitherto been exploited. There is a great deal of coal in Britain in seams of quality so poor that they are not worth mining. In other words, the price likely to be obtained for the coal does not justify the cost of getting it to the surface. The possibility of obtaining energy from this coal *in situ* is obviously of great interest.

There is also coal left in the region of disused mines. This coal may be of good quality, but for a variety of possible reasons, such as the extreme narrowness of the seam in which the remaining coal lies, it has ceased to be an economic proposition to mine it. It is possible that underground gasification might turn this unmined coal into a useful source of energy.

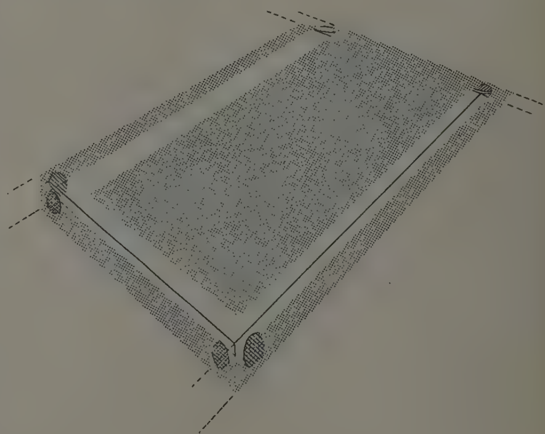


FIGURE 4

Finally, there is coal so deep in the earth that the cost of reaching it, and of overcoming the difficulties of working at the high temperatures which exist several thousand feet below the surface, makes mining it extremely expensive. Perhaps this coal may one day be exploited by underground gasification methods; at the present time, however, this possibility is little more than an interesting speculation, and the technical obstacles to be overcome before it can be achieved—if ever it can be—are formidable.

One can scarcely avoid the idea that if poor or narrow coal seams can be economically exploited

FIGURE 5 – *Photograph showing the boring of a horizontal hole to connect with vertical holes drilled from the high ground at the right of the photograph.*

FIGURE 6 – *Apparatus for the first prolonged trial of underground gasification, which began in July 1950. The compressed-air supply comes into the horizontal pipe at the valve gear near the centre of the photograph. It can then be taken to the left or to the right at will, so permitting the flow through the underground system to be reversed when desired. The thicker, shorter, horizontal pipe is an addition required to connect a meter for measuring the flow. The vertical holes are 50 ft apart.*

FIGURE 7 – *Photograph showing a second system made by connecting horizontal and vertical drillings; the vertical holes are 75 ft apart.*

by underground gasification, how much better a proposition should be the underground gasification of good coal in good seams. Consideration of this view can safely be postponed, however: at the present time more coal is wanted than can be mined, and there is a very great deal to be done in underground gasification before any serious suggestion can be made that it might, in certain circumstances, replace conventional methods of coal mining. In Britain, at any rate, underground gasification must begin on coal which would otherwise have no value. When the technical problems are overcome, it will be time to think about whether underground gasification provides in any circumstances of power production a better solution than conventional mining.

There is more than one way in which to classify the possible methods of underground gasification, but there is a convenient division into methods which require that men shall go underground to prepare the system and methods in which all the work is done on the surface. Most of the underground gasification done in Russia, and the experiments now in progress in the United States, Belgium, French Morocco, and Italy, are based upon the former method. There is some evidence, however, that the so-called percolation method, in which the whole operation is conducted from the surface, has been tried in Russia, and the assessments recently made in Britain indicate that, if this method can be successfully developed, it offers better economic prospects than the alternatives demanding direct underground workings. British workers have, therefore, started with the successful development of the percolation method as their first aim.

Given the objective of underground gasification based on surface working, the problem in the field separates into two parts. On the one hand, we need to find a good, generally applicable method of connecting the bottoms of vertical bore-holes. On the other hand, we need to study the processes of gasification and the quality of the product. On the site chosen for the initial British work, which is at Newman Spinney, near Chesterfield, the gasification part of the problem was started first. A system of the kind illustrated in figure 1 was adopted, the method used for establishing underground gasification connection being the horizontal bore-hole method illustrated in figure 2. Newman Spinney being an opencast mining site, the vertical drillings were made from the high level, and the horizontal drilling was made inwards from the more or less vertical wall left by the opencast mining operation. The problems of location involved in ensuring the conjunction of the vertical and horizontal drillings are in themselves of great interest, and will be described elsewhere in a paper which is now in preparation.

The first short runs with this system were made in April 1950, with limited success. A great deal of experience was gained then, however, so that on 13th July a prolonged run was begun with some confidence, and it was successfully continued for more than four months. The seam which is being gasified is of a most inferior kind, and would never have been mined. It is wet, and is divided into layers of shale and layers consisting half of coal and half of dirt. The calorific value of the gas produced has varied very considerably. It has at times been as low as 10 B.Th.U./cu ft, yet has attained unexpected, and to some extent unexplained, peaks, the highest of which was 497 B.Th.U./cu ft. The average calorific value for the first ten weeks was about 80 B.Th.U./cu ft, but it later dropped, so that the average over the whole period at the time of writing is about 50 B.Th.U./cu ft. The composition of the gas varies quite considerably, but specimen analyses are as follows:

1950	CO_2	O_2	CO	CH_4	C_nH_m	H_2	N_2	Cal. Val. (B.Th.U./cu ft)
	per cent. by volume							
23rd August	13·4	0·1	11·2	1·3	0·2	10·8	63·0	87
11th September	15·5	—	4·9	1·0	—	7·9	70·7	51
21st October	10·2	9·5	1·0	0·9	—	1·1	77·3	16

Although the method of horizontal drilling used to establish connection between vertical bore-holes can be conveniently adopted in certain circumstances, it is not the generally applicable method for which we are seeking in the second part of our work. The possibility of some form of mechanical mole which, starting down in a vertical direction, can drill more or less horizontally, has naturally not been overlooked. The varying success on these lines in drilling for oil has been studied, but the difficulties of this solution are such that it has, for the time being, been relinquished in favour of

the investigation of techniques dependent on the application of high pressures. The idea is that high pressure, whether pneumatic, hydraulic, or explosive, will open up the natural fissures in the coal, or lift the over-burden from it, and thereby create a passage for gas between vertical boreholes. The first experiments have been made with pneumatic pressure, and it has been found that the application of a pressure equal to that imposed on the coal seam by the overburden does, in effect, open up natural channels. Twenty per cent. of the air pumped down one vertical hole at a pressure of 100 lb/sq inch came up another vertical hole 33 ft away. Experiments of this character are still in progress. Considerably longer channels have been established, and ignition under pressure has recently been achieved.

The products of underground gasification in Britain are unlikely to have mean calorific values more than about one-fifth of that of the normal town's gas. For most of the purposes for which town's gas is used, therefore, they are not likely to supersede it. If gas from underground gasification has a future it will be as a means of heating, or as a power gas—that is, as a fuel for engines generating power. The second is the more likely application. One method would be to use it for boilers generating steam for steam-engines. Another method would be to use the gas as a fuel for gas turbines generating electrical energy. The fact that the gas is of a low calorific value is not a disadvantage, as the gas turbine can conveniently be worked on dilute fuels. The experiment at Newman Spinney is on a very modest scale—the vertical boreholes are 4 in in diameter and only about $1\frac{1}{2}$ tons of coal a day is being consumed—yet a small gas-turbine using the gas produced could generate about 50 kilowatts of electrical power.

This is not being done, and there is no plan at present to couple up a gas-turbine to an underground gasification system. The time to do this will be when the essential underground gasification problems are more fully understood. If there are any specific gas-turbine problems arising from underground gasification, they still remain to be discovered.

The gas-turbine will demand a reasonably steady supply of gas of reasonably consistent quality. The fluctuations experienced in the first Newman Spinney system would be inconvenient. When one imagines several such systems, however, forming a single supply to a gas-turbine power plant, the possibility of levelling out the fluctuations is obvious.

The best way of co-ordinating a set of systems of the kind shown in figure 1 has not yet been decided. A number of different geometrical arrangements are possible. In general terms, however, what we eventually hope to do, if our initial programme of research is sufficiently successful, is to exploit an area of hitherto useless coal by means of scores of small vertical shafts, with the products of combustion piped to gas-turbine engines generating electricity and passing it into the electricity network.

It is perhaps wise to conclude by emphasizing two points. One is that the realization of the vision just described may, even with complete technical success, be severely restricted in Britain. There are certainly many millions of tons of coal there which will never be mined by ordinary methods, but the density of our population is so high that the number of areas suitable for underground gasification may prove to be limited. There may be wider opportunities in other parts of the world.

The second point is that we are in the early stages of a relatively small-scale experimental programme, and must not develop too great an optimism on the basis of its undoubted initial success.

REFERENCES

[1] Booth, N. and Jolley, L. J. *Fuel*, **21**, 31–7, 1945.
[2] Fies, M. H. and Schroeder, W. C. *Mech. Engng. N.Y.*, **70**, 127–35, 1948.
[3] Doumenc, P. *U.N. Sci. Conf. Conserv. Utilis. Res.* (*N.Y.*, 1949) *Paper, Fuels*, 6a/3.
[4] Fies, M. H. and Elder, J. L. *Ibid.*, 6a/2.
[5] Mezzetti, A. *Riv. Combust.*, **2**, 133–7, 1948.
[6] Pani, P., Bonetti, A., and d'Alessandro, A. *Ibid.*, **2**, 142–51, 1948.
[7] Fies, M. H. *et al.* U.S. Bureau of Mines and Alabama Power Co., 1950.
[8] Doumenc, R. A. M. *Fourth Wld. Pwr. Conf.* (*Lond.*, 1950). *Sect. D2*, *Pap.* 3.

Vegetable acids in higher plants

MEIRION THOMAS

The study of vegetable acids is an old one. In the eighteenth century Scheele isolated oxalic, malic, citric, and tartaric acids. In India in the early nineteenth century Benjamin Heyne made the first observation of the diurnal variation in acid content now known to occur in the green parts of certain succulent types of plant. A few years earlier, without knowing anything about the acidity of succulent plants, de Saussure reported facts about the gaseous exchanges of a cactus which were not thought significant and which have only recently been interpreted in terms of carbon dioxide fixation as a metabolic event in acid synthesis.

When a plant organ has a sour taste, one or more di- or tricarboxylic acids will have accumulated in it to reach a not inconsiderable concentration. The titratable acidity of the sap will be high, and the *p*H relatively low, owing to the presence of free acids and their acid salts. In table I are recorded in normalities, and as *p*H values, the acidities of the saps expressed from some of the organs seen in figure 3.

TABLE I

Titratable acidities stated in normalities and as *p*H values, determined potentiometrically and by indicators (see figure 1), of saps expressed from some of the organs photographed in figure 3 and from certain other organs. (Experiments by Mr J. M. A. Brown at King's College, Newcastle upon Tyne, September 1950.)

Organ from which sap was expressed	*Normality of sap*	*pH of sap*
Lemon fruit	0·95	2·4
Red-black fruits of blackberry ..	0·23	2·7
Rhubarb petioles	0·22	3·2
Unripe grapes	0·21	3·0
Oxalis leaves	0·16	2·3
Green cooking apple	0·13	3·2
Begonia rex leaves	0·11	2·2
Begonia tuberosa, var. leaves ..	0·10	2·2
Ripe tomato fruit	0·063	4·4
Ripe Worcester Pearmain apple	0·045	3·9
Celery petioles	0·025	5·2
Root of white beet	0·025	5·8

TITRATABLE ACIDITY

The accumulation of titratable acids in the juice of ripe lemons is remarkably high—much greater than in any of the other organs examined. In some plant organs the accumulation may be even lower than in celery petioles and the root of white beet; it is, however, not improbable that titratable acidity would be measurable in the saps of all plant organs at all stages in their development and under all environmental conditions.

For a given plant, heredity determines the nodal value about which the titratable acidity of an expressed sap will vary. The sourest apple will never be as acid as the least sour lemon, and, among apples, cooking varieties, even when ripe, will be more acid than a dessert apple such as Worcester Pearmain in late September.

Apart from inherited individual differences in a given variety of plant, soil and climate will exert an influence. Nurtured under unfavourable conditions, the choicest grape may remain disagreeably tart by retaining its accumulated acids.

The results of quantitative experiments give exact expression to the fact vouched for by the sense of taste that, in aging, a plant organ often becomes less sour. For example, in one experiment performed in the United States, it was found that the acidity of the juice of Valencia oranges decreased from 0·39N to 0·13N as the fruit ripened.

THE INDIVIDUAL ACIDS

In the legend to figure 3, some facts are recorded concerning the distribution of nearly all the individual di- and tricarboxylic acids listed below.

Oxalic acid
$HOOC.COOH$

Succinic acid
$HOOC.CH_2.CH_2.COOH$

Fumaric acid
$HOOC.CH = CH.COOH$

Malic acid
$HOOC.CH_2.CHOH.COOH$

Oxalacetic acid
$HOOC.CH_2.CO.COOH$

Tartaric acid
$HOOC.CHOH.CHOH.COOH$

α-Ketoglutaric acid
$HOOC.CH_2.CH_2.CO.COOH$
Oxalsuccinic acid
$HOOC.CH_2.CH(COOH).CO.COOH$
Citric acid
$HOOC.CH_2.C(OH)(COOH).CH_2.COOH$
iso-Citric acid
$HOOC.CH_2.CH(COOH).CHOH.COOH$
cis-Aconitic acid
$HOOC.CH_2.C(COOH) = CH.COOH$
Tricarballylic acid
$HOOC.CH_2.CH(COOH).CH_2.COOH$

Most of these facts have been known for a long time. Scheele, in the eighteenth century, succeeded in separating oxalic, malic, citric, and tartaric acids from plants or plant products, and knowledge concerning the distribution of these and the other acids mentioned in the legend (except *iso*-citric acid) increased sporadically during the nineteenth century and the early years of the present century.

Iso-citric acid was synthesized by Fittig in 1889, but its occurrence in nature was not demonstrated until 1927, when Nelson extracted it from blackberry fruits and prepared its hydrazide. Nelson found that five-sixths of the acidity of the fruits was attributable to *iso*-citric acid. He also reported the presence of this acid in the leaves. It is now believed that *iso*-citric acid plays an essential part in the aerobic metabolism of all living cells.

All plant saps may contain a mixture of di- and tricarboxylic acids, but one or more may predominate. Thus oranges and apples contain citric and malic acids in easily recognizable amounts, and other acids in much smaller amounts. In oranges, citric acid reaches a much higher concentration than malic acid: in apples malic acid predominates. These are the two acids which have been most frequently found in considerable accumulation in edible organs. Accumulations of tartaric acid appear to be rare. We have insufficient data about *iso*-citric acid to venture a general statement. It accumulates in high concentrations in *Bryophyllum* leaves (see below). Free oxalic acid has a wide distribution, and in certain organs (e.g. rhubarb leaves) reaches concentrations high enough to render them poisonous.

TOTAL ACIDITY

The anions of di- and tricarboxylic acids accumulate not only in free acids and acid salts, but also in normal salts, some of which (e.g. potassium and ammonium salts) are soluble, and one at least (*viz.* calcium oxalate, of wide distribution) is insoluble. In addition, vegetable acids combine with nitrogenous bases, such as alkaloids. Total acidity is a measure of the acid anion concentration, and is clearly the best index of the intensity of acid metabolism. In rhubarb petioles, total acidity may be double the value of titratable acidity. In these petioles, and indeed in plant organs in general, the synthesis and accumulation of the acid anions occur gradually as the organs grow. Simultaneously, nitrate, sulphate, and phosphate anions absorbed from the soil are used in anabolism. The residual cations combine with the carboxylic anions. One function of acid synthesis, therefore, may be the control of the hydrogen ion concentration of cell sap.

HYDROGEN ION CONCENTRATION

All expressed plant saps are acid to litmus. In general their *p*H values are less than 5·5, but relatively high values have been reported for saps from certain leaves, e.g. fig (6·8), spinach (6·5). Values as low as 1·5 have been found for *Begonia* and *Oxalis*. The range of values in table I is from 2·2 to 5·8 (see also figure 1). Like those for titratable acidity, these values are determined in part by inheritance, and in part by the age of an organ and the environmental conditions prevailing during development. Thus the *p*H of lemon juice is probably always less than 3 and greater than 1, and that of beet juice greater than 5 and less than 7. Within these limits there may be much variation. In one experiment (see p. 160) it was found that, during the ripening of Valencia oranges, the *p*H of the juice increased from 2·9 to 3·8, owing to the consumption of titratable citric acid.

It is noteworthy that the normality and the hydrogen ion concentration of saps are not always directly related. This is owing in part to the different degrees of buffering of the saps, and in part to differences in the dissociation constants of the accumulating acids (see table II).

TABLE II

Dissociation constants at 25° C

Oxalic acid	$6{\cdot}5 \times 10^{-2}$
Malic acid	4×10^{-4}
Tartaric acid	$9{\cdot}7 \times 10^{-4}$
Citric acid	$8{\cdot}7 \times 10^{-4}$

The normality of lemon juice may be nearly ten times greater than that of sap from *Oxalis* or *Begonia* leaves; but the *p*H of these saps is usually less than that of lemon juice, because oxalic acid,

with a relatively high dissociation constant, accumulates predominantly in them, whereas citric acid, a weak acid, is mainly responsible for the titratable acidity of the lemon juice.

ACID METABOLISM

Whether or not, over a period, an acid will accumulate or disappear, will be determined by the relative rates of its metabolic production and consumption. In many plant organs the rate of production for one or more acids must, on balance over the growing season, exceed the rate of consumption. However, in ripening fruits consumption is usually more rapid than production.

Certain plants are specialized in that they show diurnal variation in acidity. Their behaviour will be considered below under the heading 'Crassulacean acid metabolism'. There is no reason to believe that the biochemical mechanisms governing the production and consumption of acids in these plants are essentially different from those which operate in other plants.

Indeed, it is not improbable that the enzymic systems at work, and the sequence of changes, in the higher plants are very similar to those which have, in recent years, been elucidated by the brilliant investigations of Krebs, Martius and Knoop, Wood and Werkman, Ochoa, and others, on animal tissues and bacteria. It has been established that, in their aerobic metabolism, animal and bacterial cells can produce and consume di- and tricarboxylic acids. In general, consumption is relatively the more rapid process, and the acid molecules have short lives. For this reason the phenomenon of the metabolism of these acids in animal and bacterial cells was overlooked until about fifteen years ago. Only in green plants and certain mould fungi had considerable accumulations been found, which is why these acids were called vegetable acids. We now have more detailed biochemical information about the metabolism of vegetable acids from studies performed on animal tissues than from those carried out on plants. Some of this information is summarized below under the heading tricarboxylic acid cycle.

CRASSULACEAN ACID METABOLISM

The peculiarities of this form of metabolism are stated in the legend to figure 4. The phenomenon of diurnal variation in acidity was first decribed in 1813 by Benjamin Heyne in a letter to A. B. Lambert, vice-president of the Linnean Society. Heyne had tasted *Bryophyllum* leaves in India, and wrote: 'The leaves of the *Cotyledon calycina*, a plant called by Mr Salisbury *Bryophyllum calycinum*, which on the whole have a herbaceous taste, are in the morning as acid as sorrel, if not more so; as the day advances, they lose their acidity, and are tasteless about noon and become bitterish towards evening.'

The results recorded in table III and figure 2 give the changes in titratable acidity and *p*H in an experiment on leaves taken from *Bryophyllum* plants similar to the one illustrated in figure 4. The temperature was reduced during the dark period, because it is known that low temperatures may favour dark acidification.

TABLE III

Diurnal variation in acidity of leaves of Bryophyllum calycinum. (*J. M. A. B., Sept.* 1950)

Conditions before analysis	*Normality of sap*	*p*H *of sap* (*see figure* 2)
(*a*) 26 hours illumination. Room temperature	0·03	5·05
(*b*) 26 hours illumination and 24 hours dark. 10° C	0·08	4·56
(*c*) 26 hours illumination, 24 hours dark, and 5 hours illumination. Room temperature	0·02	5·40

*p*H values were previously determined potentiometrically.

Numerous quantitative investigations have been made of dark acidification and light deacidification, culminating in more recent times in those of Bennet-Clark in Britain, Wolf at Leipzig, and Vickery and Pucher and their colleagues at Connecticut. Vickery and his colleagues showed that the principal acids in *Bryophyllum* leaves are *iso*-citric, malic, and citric. *Iso*-citric acid may reach a high concentration. Indeed, *Bryophyllum* is now sometimes grown to serve as a source of this acid for chemical and biochemical experiments. However, diurnal fluctuation in *iso*-citric acid is slight. Acidification is mainly due to the accumulation of malic acid, and deacidification to the depletion of the store. In the dark, this acid is produced more rapidly than it is consumed; in the light, consumption is the faster process. From Newcastle has come a suggested explanation for these changes in rate, and also some experimental evidence in support of it.

The investigators named in the last paragraph have established beyond reasonable doubt that malic acid is derived from carbohydrate. After

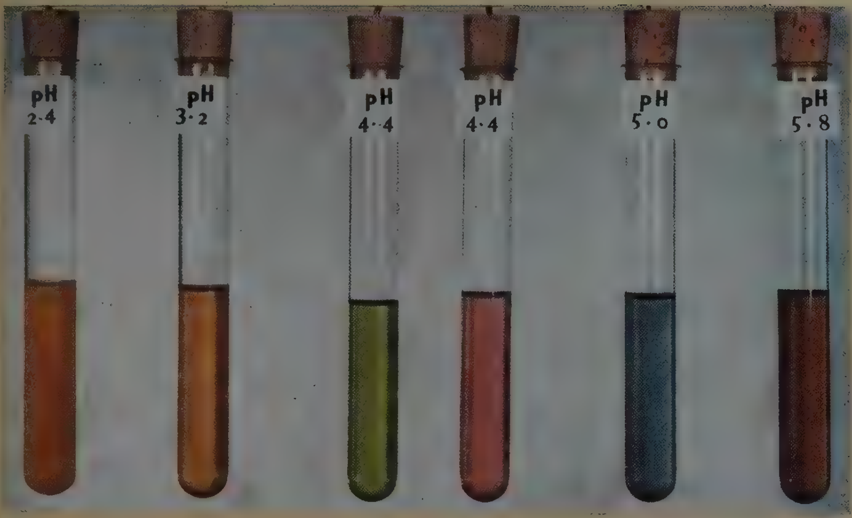


FIGURE I – *Colours given by appropriate indicators with certain expressed saps (see table I) whose pH values had been determined potentiometrically.* (a) *Lemon juice and thymol-blue;* (b) *Rhubarb juice and brom-phenol-blue;* (c_1) *Tomato juice and brom-cresol-green;* (c_2) *Tomato juice and methyl-red;* (d) *Celery juice and brom-cresol-green;* (e) *Beet juice and brom-cresol-purple.*

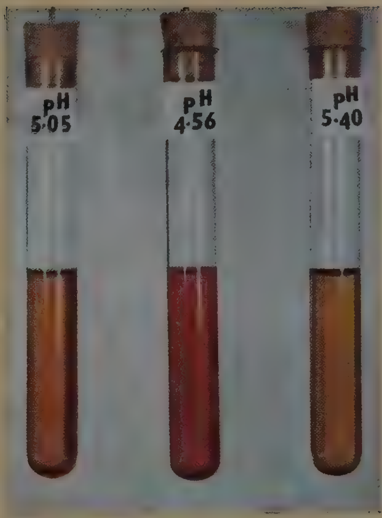


FIGURE 2 – *Colours given when methyl-red was added to saps expressed from* Bryophyllum *leaves treated respectively as described in table III* (a), (b) *and* (c).

IGURE 3 – *The plants shown in this collection have the power of ccumulating one or more vegetable acids, but not the property of diurnal ariation in acidity. The specimens include apple, rhubarb petiole, obacco-leaves, and ivy-leaved* Pelargonium *(malic acid); lemon (citric cid); fruit and leaves of blackberry* (iso-*citric acid); fruit and leaves f grape (tartaric acid); leaves of* Begonia, Oxalis, *and rhubarb (oxalic cid); unripe beet (aconitic and tricarballylic acids).*

FIGURE 4 – *The plants shown in this collection possess the peculiarity of accumulating acids in the dark at certain seasons and consuming them again during the day. The plants are (from left to right) as follows: (Top shelf)* Bryophyllum calycinum, Kalanchoe *sp.; (Second shelf)* Crassula lactea, Opuntia cylindrica; *(Third shelf)* Echeveria *sp.,* Opuntia Engelmannii; *(Bottom shelf)* Sedum praealtum, Crassula arborescens, Sempervivum *sp.*

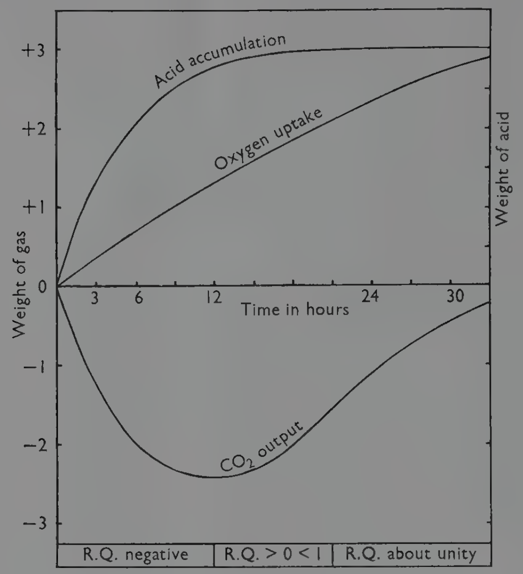


FIGURE 5 – *The curves give a generalized representation of the results of Newcastle experiments performed by Beevers and Ranson. Carbon dioxide and oxygen are simultaneously absorbed from a gas mixture containing oxygen and* 5 *per cent. carbon dioxide during intensive dark acidification of plants showing Crassulacean acid metabolism. The values of respiratory quotients are negative during this phase. Later, when the rate of acidification declines, these values become positive, gradually rising from zero to unity. Normal respiratory gaseous exchange then occurs according to the equation:*

$$C_6H_{12}O_6 + 6O_2 = 6\ CO_2 + 6\ H_2O.$$

When values of the respiratory quotients lie between zero and unity, some of the respiratory carbon dioxide is consumed in the synthesis of malic acid, and therefore fails to escape. A possible overall equation for this synthesis is

$$C_6H_{12}O_6 + 2CO_2 = 2\ C_4H_6O_5.$$

When these values are negative, carbon dioxide absorbed by the leaves, in addition to respiratory carbon dioxide, is consumed.

glycolysis, the Wood and Werkman reaction (see figure 6) could operate on pyruvic acid or its phospho-derivative, leading either to the synthesis of oxalacetic acid, and the reduction of this compound to yield malic acid by the successive action of the enzymes oxalacetic carboxylase and malic dehydrogenase, or to the direct synthesis of malic acid by what is called the malic enzyme.

The Wood and Werkman reaction involves the fixation of carbon dioxide. The first proof that carbon dioxide is an essential metabolite in the biosynthesis of dicarboxylic acids was obtained in experiments on bacteria and pigeon's liver. A consideration of certain recorded facts relating to the gaseous exchanges of plants showing Crassulacean acid metabolism strongly suggested that the fixation of respiratory carbon dioxide accompanied acid accumulation in the dark. Some 150 years ago, Th. de Saussure, in his *Recherches Chimiques sur la Végétation*, showed that cactus shoots, placed after sunset in a closed space, absorb oxygen without giving off carbon dioxide; thus the respiratory quotient is zero. Numerous experiments performed at Newcastle in 1946 and subsequently, and the results obtained in Bonner's laboratory in California, have provided evidence of this fixation.

When leaves which do not show Crassulacean acid metabolism are placed in the dark in a gas mixture containing air enriched with carbon dioxide, oxygen is absorbed, carbon dioxide is liberated and the value of the respiratory quotient is usually about unity. In striking contrast: when, at the outset of a dark period, acidification is most intense in leaves which accumulate malic acid in the dark, carbon dioxide and oxygen may be simultaneously absorbed (see figure 5). The CO_2 output may be regarded as negative, which implies a negative value for the respiratory quotient. Actually this singular fact was observed nearly 150 years ago by Th. de Saussure, who showed that in the dark a cactus in air enriched with carbon dioxide absorbed oxygen and carbon dioxide simultaneously. The few later workers who took notice of this effect lightly dismissed it as an effect of solubility and of no physiological significance. Indeed, the 'de Saussure effect' (as the present writer and Wolf have independently suggested that the absorption of carbon dioxide during dark acidification should be called) could not have been interpreted until the discovery of the Wood and Werkman reaction.

Light deacidification in Crassulacean acid metabolism is attributed to the virtual stopping of the carbon dioxide supply to centres of acid synthesis in green leaves. In the light this gas is preferentially consumed by the chloroplasts in photosynthesis, and little or none is available for the Wood and Werkman reaction. Acid consumption continues, and as the stores are not replenished the titratable acidity of sap declines and the *p*H value rises.

THE TRICARBOXYLIC ACID CYCLE

Sound evidence has been obtained for the view that in animal tissues the aerobic katabolism of carbohydrate predominantly occurs in a manner closely similar to that outlined in figure 6.

Phosphorylative glycolysis yields pyruvic acid

$(CH_3.CO.COOH)$.

This compound or its phospho-derivative may condense directly with oxalacetic acid already present in the cell to form *cis*-aconitic acid. Alternatively, the pyruvic acid may first be converted into acetyl phosphate before the condensation takes place. The condensation is an oxidative decarboxylation. A series of hydrations, dehydrogenations, and decarboxylations then take place, each under enzymic control. The smooth working of the dehydrogenases depends upon a continuous oxygen uptake. *Cis*-aconitic acid is oxidatively decomposed with liberation of carbon dioxide and water, and with the regeneration of oxalacetic acid, which can once again take its catalytic part in the cycle of changes indicated by the heavy lines in figure 6.

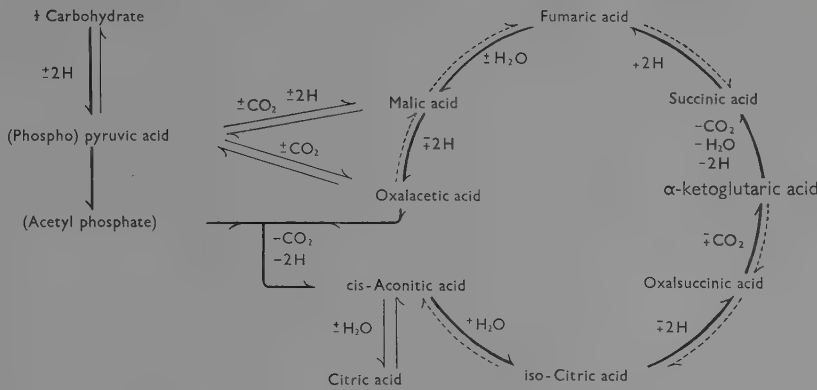


FIGURE 6 – *A representation of the tricarboxylic acid cycle, indicating possible methods by which vegetable acids are produced and consumed. All the individual reactions, except the oxidative decarboxylations leading to the production of* cis-*aconitic and succinic acids, have been shown to be reversible.*

It is noteworthy that of the acids believed to be produced in this cycle, *cis*-aconitic, citric, *iso*-citric, succinic, fumaric, and malic acids may accumulate in plant tissues (see p. 160). It is a useful working hypothesis, therefore, that they may be produced in plants by mechanisms similar to those which have been studied in animal tissues, and in the same sequence. The body of evidence supporting this view is not yet very substantial. The accumulation in a plant tissue of a certain acid (e.g. citric acid in citrus fruits, *iso*-citric in the blackberry fruits, fumaric acid in fumitory) would mean that the conditions in the cell, determined by the inheritance of the plant, the stage of development, and environmental conditions, favour the enzymic production rather than the enzymic consumption of the acid.

It is not yet known whether any connection exists between the formation of oxalic, tartaric, and tricarballylic acids and the reactions occurring in the tricarboxylic acid cycle. However, there is strong evidence that some of the substances produced in the cycle of changes are intermediate compounds in the formation of certain amino-acids and other important metabolites. Research during the last fifteen years has firmly placed the vegetable acids in a central position in theories concerning the chemical economy of all living cells.

BIBLIOGRAPHY

BENNET-CLARK, R. A. *New Phytol.*, **32**, 37, 128, 197, 1933.

Idem. *Ann. Rev. Biochem.*, **18**, 639, 1949.

BONNER, W. and BONNER, J. *Amer. J. Bot.*, **35**, 113, 1948.

DE SAUSSURE, T. 'Recherches chimiques sur la Végétation.' 1804.

HEYNE, B. *Trans. Linn. Soc. Lond. Zool.*, **11**, 213, 1815.

KREBS, H. A. *Adv. Enzymol.*, **3**, 191, 1943.

NELSON, E. K. *J. Amer. Chem. Soc.*, **49**, 1300, 1927.

OCHOA, S. *J. biol. Chem.*, **159**, 243, 1945.

PAECH, K. 'Biochemie und Physiologie der Sekundären Pflanzenstoffe.' Berlin, 1950.

PUCHER, G. W., VICKERY, H. B., ABRAHAMS, M. D., and LEAVENWORTH, C. S. *Plant Physiol.*, **24**, 610, 1949.

SMALL, J. 'Hydrogen Ion Concentration. Protoplasma Monographien.' Berlin, 1929.

THOMAS, M. 'Plant Physiology' (Chapter XV). 1947.

Idem. *New Phytol.*, **48**, 390, 1949.

THOMAS, M. and BEEVERS, H. *Ibid.*, **48**, 421, 1949.

THURLOW, J. and BONNER, J. *Arch. Biochem.*, **19**, 509, 1948.

VICKERY, H. B. and PUCHER, G. W. *Ann. Rev. Biochem.*, **9**, 529, 1940.

WERKMAN, C. H. and WOOD, H. G. *Adv. Enzymol.*, **2**, 135, 1942.

WOLF, J. *Planta*, **37**, 510, 1949.

Book reviews

PARTICLE ACCELERATORS

Machines Atomiques, *by Maurice E. Nahmias. Pp.* 310, *with numerous half-tones and line diagrams. Editions de la Revue d'Optique Théorique et Instrumentale, Paris.* 1950. *Bound* 1,480 *francs; paper cover* 1,200 *francs net.*

This book is a much-expanded version of an earlier work (*Le Cyclotron*, 1945). It describes all the familiar particle accelerators and some unfamiliar ones, such as a plant in Switzerland where an attempt was made to build a 10 MV supply by tapping the electric charge of thunder clouds. Concise and effective descriptions are given for each system, with derivations of the necessary equations of motion of the accelerated particles. In each case appropriate numerical examples are given, applicable to existing machines, which help a great deal in appreciating the significance of the formulae produced. The principles and properties of atomic piles are briefly but adequately described.

Interspersed among the descriptions of machines are discussions of the types of nuclear reactions which they make possible. This helps to make the book interesting and easy to read. There is no doubt that it will prove most useful to any physicist entering a laboratory concerned with the production of high-energy particles.

Some of the figures quoted should not be relied on; for example, the Birmingham cyclotron is 155 cm, not 100 cm as stated, and the voltage and current quoted for the Birmingham proton synchrotron are both ten times too low. It is a great pity that the book has no index.

J. H. FREMLIN

ORGANIC CHEMISTRY

Principles of Ionic Organic Reactions, *by Elliot R. Alexander. Pp.* 318. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1950. 44*s. net.*

In this book the author strives to find common principles for a large number of reactions resulting in the elimination or addition of groups. Beginning with simple rearrangements such as the formation of carbonium ions, the discussion embraces more complex processes such as the Grignard and Wurtz reactions, Claisen condensations, diazonium coupling, and double-bond migration. These principles are based on the electronic structure of the bonds, their permanent and induced polarization, resonance, and other effects, and they are discussed in qualitative and non-mathematical language. As the book is intended for organic chemists, the exclusion of mathematics is an advantage. However, the systematic omission of fundamental physico-chemical data, such as free energies, reaction rates, and temperatures, will be regretted by many modern organic chemists. A knowledge of these data would greatly facilitate the understanding of reactions, especially as any discontinuities in their trend are usually indicative of a change of reaction mechanism.

The book as a whole represents an extensive survey of ionic organic reactions and their significant literature up to 1949. It is well written and easy to follow, and the author must be congratulated on having produced a book which constitutes a valuable addition to the library of every organic chemist.

E. GLUECKAUF

A BOOK OF TABLES

The Scientist's Ready Reckoner, *by W. Roman. Pp.* 142. *Dr W. Junk, The Hague, Holland.* 1950. *fl.* 6.50 *net.*

This is a somewhat unusual book of tables. It is especially fitted for the use of chemists and physicists working in analytical laboratories, and it may prove useful to research workers in technical institutions. The tables published are: (1) a list of international atomic weights and their logarithms; (2) and (3) tables of atomic weights, followed by a fairly comprehensive list of compounds and of the weights of frequently occurring radicals; (4) and (5) gravimetric and volumetric factors and their logarithms; (6) specific gravities of liquids and solutions; (7) a table for the conversion of temperatures of the Kelvin scale into Fahrenheit and Centigrade scales, and conversely; (8) and (9) tables of four-figure and five-figure logarithms.

The book is beautifully produced, but there are one or two minor points which it may be well to consider here.

There is a tendency nowadays to cut down the use of rules in the setting-out of tables, and to rely more on the grouping of the rows and columns by the use of spaces. The inconvenience caused by insufficient breaking up of the blocks of figures is especially evident in table (7) for temperature conversion. Surely the use of the low point to indicate decimal fractions is unusual; a high point is the usual practice, and a low point indicates multiplication.

The editor proposes to publish other parts; Part II is scheduled to contain 'a comprehensive list of conversion factors for metric, international, and national weights and measures, together with their logarithms.'

Natural logarithms—that is, logarithms to the base *e*—should never be called Napierian logarithms. Napier's logarithms, though related to natural logarithms, were very different.

We trust that Part I will have a wide circle of users. It is, as we have said, remarkably well produced, is easy to handle, and is issued at a reasonable price.

ALLAN FERGUSON

TEMPERATURE AND HUMAN LIFE

Temperature and Human Life, *by C. E. A. Winslow and L. P. Herrington. Pp.* 272. *Princeton University Press, U.S.A.; Oxford University Press, London.* 1949. 28*s. net.*

The study of the reactions of the human body to the conditions of its environment may be said to have been initiated by Sanctorius in 1614, in *Ars de Medica Statica*, but advance was slow during the following three centuries. The early development of the profession of the heating and ventilating engineer was based on the erroneous idea that the purpose of ventilation was to remove or dilute the organic poisons formed in the breath, and it was in a sense an accident that ventilation removed the excess heat from the body.

The book under review gives a coherent and interesting account of the work done in the United States, during the present century, by the American Society of Heating and Ventilating Engineers (established some thirty years ago), and later in the authors' own laboratory, the John B. Pierce Laboratory of Hygiene (established in 1933). The work done in the latter laboratory, under the directorship of Dr Winslow, forms the main basis of this book, but the work done elsewhere is also reviewed, giving a clear picture of our present knowledge of experimental hygiene. The reactions of the human body to a wide range of air temperature, humidity, air speed,

radiation from surrounding solid bodies, and degree of exertion, are described with outstanding clarity.

The history of the development of our present knowledge is presented in an interesting manner, and we find here some little-known facts concerning early attempts to understand the basic facts of environmental hygiene. For example, according to Heidel, a Greek, Erasistratus (in the third century B.C.), experimented with a respiration calorimeter, finding the loss in weight of fowls placed in a jar, due to what we now call insensible perspiration.

The lay reader will perhaps be surprised to find that while the metabolic rate is proportional to the area of skin in any particular mammal, it is subject to only very slight variation in different mammals except the very largest, such as the horse or the elephant, when observed in similar conditions.

For thermal balance of the human body, the rate of production of heat within the body must be balanced by the combined effects of the loss of heat by evaporation, and the gain or loss of heat by convection and by radiation. The third chapter of this book discusses the items in the thermal budget, and describes the reactions of the body to meet varying conditions in the environment; it is very fully illustrated by tables and diagrams.

Four further chapters deal with the protective influence of clothing, the problems of air conditioning (which are physical and not chemical, cutaneous and not respiratory), the methods of air conditioning, and the effects of climate and weather on health.

Many of the problems discussed in this book became urgent during the war, notably those concerned with the design of clothing suitable for men exposed to extreme conditions of temperature and of physical effort. These problems are discussed in some detail, in a manner which gives a clear insight into the methods of applying the results of the experiments made in the laboratory to both indoor and outdoor life in varying conditions.

The book ends with a well-selected bibliography containing 151 entries, covering all aspects of the material discussed in the seven chapters.

The lucid style of writing, and the careful selection and discussion of the matter to be included, make this book a valuable contribution to the literature of experimental hygiene. It fills a notable gap in this literature, a gap which has in the past made it almost impossible for anyone but an expert worker to acquire a reasonable knowledge of what was definitely known, and of what yet remained to be found. Even with a meagre knowledge of physiology, the reader of this book will be able to grasp most of its arguments and conclusions. At the same time there are parts of the book which will make a special appeal to the expert. Thus in Chapter VII will be found some facts which will appeal to the expert epidemiologist, in the discussion of climate, weather, and health.

D. BRUNT

KINETIC THEORY OF LIQUIDS

A General Kinetic Theory of Liquids, *by M. Born and H. S. Green. Pp.* 98. *Cambridge University Press, London.* 1949. 10*s.* 6*d. net.*

This is not a book for the layman. It can, indeed, be appreciated by the expert only after concentrated study. It is a reprint of six papers from the *Proceedings of the Royal Society.* The first four are devoted to the general kinetic theory of liquids, and their main achievement is the development of a mathematical technique to deal with the special features of a liquid—that the molecules do not keep the same set of neighbours as in a solid, and yet do not move nearly independently of one another as in a gas. The theory leads to a distinction between different legitimate uses of the words 'pressure' and 'temperature' in dealing with a moving liquid. Such distinctions are elaborated in the fifth paper, which deals with the kinetic approach to thermodynamics. The methods are applied in the last paper to the properties of liquid helium, in an attempt to understand its remarkable properties. The book is not intended as a comprehensive treatise on liquids, but rather as a preliminary introduction to the potentialities of a new approach.

M. H. L. PRYCE

JAN INGENHOUSZ

Jan Ingenhousz, Plant Physiologist, with a History of the Discovery of Photosynthesis, *by Howard S. Reed. Pp.* 105, *with* 8 *plates. Chronica Botanica Company, Waltham, Mass.; Wm. Dawson and Sons, London.* 1949. $3 *net.*

Dr Reed has earned the gratitude of botanists by devoting his retirement to studies in botanical history. His first book was, perhaps, too ambitious to satisfy most of his readers. The present book is a reprint of Ingenhousz's *Experiments on Vegetables*, with editorial comments by Dr Reed, and it will be welcome in every botanical library. Ingenhousz published this book in English in 1779. It is a landmark in the history of plant physiology, for it contains the evidence that plants 'correct foul air unfit for respiration' only in light, and that this activity is centred in the leaves.

Ingenhousz's essay is refreshing to read for three reasons. In the first place, it is written with an unaffected charm which makes one realize that in order to be lucid and unambiguous it is not really necessary to adopt the gawky style affected by many modern research workers in their papers. In the second place, it displays a courtesy toward other workers in the same field (especially to Priestley) which is an example of the highest traditions in science. In the third place, it serves to remind physiologists that the teleological approach, lamentable as it may be to the philosophers of biology, is not incapable of leading to scientific results of the first importance.

ERIC ASHBY

RELATIVITY FOR THE EXPERIMENTALIST

Weltsystem, Weltäther, und die Relativitätstheorie, *by Karl Jellinek. Pp.* xvi + 450. *Wepf and Company, Basel.* 1949. 45 *Swiss francs.*

The author says that most men of science who are primarily experimentalists have only hazy notions about relativity, with a certain amount of uneasiness and confusion; they wonder if it is necessary to unlearn the naïve conceptions of space and time, and whether the question of the existence or non-existence of the aether has been definitely answered. His book is addressed to such readers, and also to philosophers, rather than to the professional theoretical physicists who can understand Eddington's treatise. His aim is something between a work of popularization and a mathematical textbook. With this end in view, he avoids as far as possible the abstract four-dimensional space-time continuum; considerable space is given to a discussion of such topics as the Michelson-Morley experiment, the Kennedy-Thorndike experiment, aberration, and the Fresnel-Fizeau effect. He does not enter deeply into the general theory of relativity, choosing rather to treat

specific problems such as the homogeneous gravitation-field and the field of the Sun.

On the historical side the author is weak, his references being often to other textbooks rather than to original papers. However, if the work is not too long for its purpose, it should prove decidedly useful. E. T. WHITTAKER

NUCLEAR INFORMATION CHART

Trilinear Chart of Nuclear Species, *by William H. Sullivan. Art work by Kay Brewster. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 20*s. net.*

By the artificial synthesis of heavy nuclei, the tally of chemical elements is being pushed towards a hundred; each element has isotopic forms of differing nuclear constitution, and the total number of identified nuclear species is now about nine hundred, most of them being artificially produced and unstable. About some of the nine hundred we know only their nuclear constitution (i.e. the numbers of neutrons and protons they contain), and, for the unstable ones, their mode of radioactive disintegration. For others, detailed information is available on such matters as the exact mass, the nuclear angular momentum, and the energies of particles or photons emitted at disintegration.

It has been customary to summarize the principal properties of atomic nuclei on a chart in which each nuclear species is allotted one square of a gridiron pattern. The position of the square corresponds to the neutron-proton constitution of the nucleus, while numbers and symbols within the square give as many facts about the nucleus as are known, or as can conveniently be compressed into (for example) half a square inch. If a move to the east represents an additional proton and a move to the north an additional neutron, then a beta-transformation between two nuclei (i.e. nuclei of equal mass number) corresponds to a diagonal move to the south-east. Charts of this kind, compiled by E. Segrè, have set the pattern for most of those hitherto published.

In the chart under review, the neutron and proton co-ordinates are not at right angles but at 60° to one another. Constant-mass lines being represented by moves in the third direction, at 60° to both the neutron and the proton axes. The spaces are no longer squares of a grid, but hexagons of a honeycomb. Stability or instability, and in the latter case the mode(s) of decay, are shown by colour codes, thus leaving space for a little more numerical and symbolical information. The chart is well printed, but much of the type is too small for easy reading.

The trilinear arrangement tends to equalize the emphasis given to neutron content, proton content, and neutron + proton content of a nucleus, though none of these is quite so clearly displayed as are neutron content and proton content on the usual form of chart. Whether the arrangement is an improvement or not depends upon the user's principal interests, just as Mercator's projection may be either superior or inferior to others for the different uses of a map.

P. B. MOON

HIGH-PRESSURE PHYSICS

The Physics of High Pressure, *by P. W. Bridgman. Pp.* 445, *with various half-tone and line illustrations. G. Bell and Sons Limited, London.* 1950. 35*s. net.*

To the specialist no review of this book is necessary; he will have it. Scientific workers in many fields will find the book stimulating and valuable. Almost anyone with a spark of scientific curiosity will enjoy the account of pioneering effort written by the pioneer. The technical difficulties met and mastered in producing pressures up to 100,000 kg/cm² are vividly presented; so is the wonder at the discovery of strange effects. Steel becomes so ductile at 25,000 kg/cm² that it shows something like infinite elongation at the neck; many liquids increase their viscosity millions of times and become solids.

The historical introduction is followed by three chapters on technique, followed by separate chapters on the PVT relations in fluids, compressibility of solids, melting phenomena, polymorphic transitions, electrical resistance of metals and solids, thermoelectric phenomena, thermal conductivity, and viscosity. The final chapter is a miscellany which includes the effect of pressure on solubility, the electrical conductivity of solutions, dielectric constant and strength, index of refraction and other optical constants, e.m.f. of a cell, magnetic permeability, rigidity, and Young's modulus. A supplement on recent work concludes the book.

Bridgman's general method is to survey the main effects of pressure on the various physical and chemical properties of matter, to show that theory fails in most cases to predict or explain the whole range of change observed, and to sketch a qualitative theory of his own, for which he makes modest claims. In the end the field is littered with dead theories; Andrade's theory of the variation of viscosity with pressure is a notable exception. The time is ripe, if not overdue, for a new, unifying concept in high-pressure physics.

D. O. SPROULE

NUCLEUS AND ELECTRONS

Interaction entre le Noyau et son Cortège Electronique—Réunions d'études et de mises au point tenues sous la présidence de Louis de Broglie. *Pp.* 198, *with line drawings. Editions de la Revue d'Optique Théorique et Instrumentale, Paris.* 1949. 800 *francs.*

This book contains a series of papers on some interactions between the nucleus and the surrounding electrons of the atom, the best known of which is the phenomenon known as 'internal conversion.' The papers relate to both the theoretical and the experimental sides of these problems, but on the whole the former predominates. The audience which the writers have in view seems to be experimentalists with some theoretical knowledge who wish to gain a better idea of the theory. Louis de Broglie himself contributes an admirable outline of the basic principles, and the first paper, by R. Daudel, extends this to particular problems, making use of de Broglie's new theory of light, which envisages the photon as a particle of small but not zero rest-mass and capable of three states of spin. Space is full of photons 'annihilated' and unobservable, but capable of being called back to life, like electrons from Dirac's sea of states of negative energy. The consequences of this theory, as far as the subject matter of this book is concerned, seem not to differ profoundly from those of the more usual treatment.

The general trend of the book is to point out that the interaction between the central core of the atom, the nucleus, and the electrons which surround it is more varied and less one-sided than is often supposed, and that in particular the absence of some or all of the external electrons may affect the radioactive behaviour of the nucleus. These effects are admittedly small and in some cases open to question, but something of the kind must happen.

G. P. THOMSON

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

The History of Nature, *by C. F. von Weizsäcker. Pp.* 180, *with eight half-tone plates. Routledge and Kegan Paul Limited, London.* 1951. 12*s.* 6*d. net.*

Introducing Astronomy, *by J. B. Sidgwick. Pp.* 259, *with half-tone and line illustrations. Faber and Faber Limited, London.* 1951. 15*s. net.*

The Origin of the Earth, *by W. M. Smart. Pp.* 239, *with many half-tone and line illustrations. Cambridge University Press, London.* 1951. 12*s.* 6*d. net.*

BIOCHEMISTRY

The Biochemistry of Fish—Biochemical Symposia No. 6, *edited by R. T. Williams. Pp.* 105, *with several line diagrams. Cambridge University Press, London.* 1951. 12*s.* 6*d. net.*

BOTANY

Mycotrophy in Plants, *by Arthur P. Kelly. Pp.* 233, *with several line diagrams. Chronica Botanica Company, Waltham, Mass., U.S.A.; Wm. Dawson and Sons Limited, London.* 1950. $4.50 *net.*

The Rhododendron Leaf, *by J. M. Cowan. Pp.* 120, *with colour and half-tone plates. Oliver and Boyd Limited, Edinburgh.* 1951. 21*s. net.*

Seaweeds and their Uses, *by V. J. Chapman. Pp.* 287, *with numerous half-tone and line illustrations. Methuen and Company Limited, London.* 1950. 25*s. net.*

CHEMISTRY

Advanced Organic Chemistry, *by Reynold C. Fuson. Pp.* 669. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1950. 64*s. net.*

Chemical Thermodynamics, *by Frederick D. Rossini. Pp.* 514. *John Wiley and Sons Limited, New York; Chapman and Hall Limited, London.* 1950. 48*s. net.*

Chimie Minérale Théorique et Expérimentale (Chimie Electronique), *by F. Gallais. Pp.* 810, *with* 42 *illustrations. Masson et Cie, Paris.* 1951. *Paper cover,* 2400 *francs; linen cover,* 2800 *francs.*

Colloidal Dispersions, *by Earl K. Fischer. Pp.* 387, *with several line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1951. 60*s. net.*

Fluoreszenz organischer Verbindungen, *by Theodor Förster. Pp.* 312, *with several line diagrams. Vandenhoeck und Ruprecht, Göttingen.* 1951. *Paper cover,* 29.50; *bound,* 32.50 *DM.*

Handbook of Antibiotics, *by A. L. Baron. Pp.* 303. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1951. 52*s. net.*

Les Méthodes d'Analyse des Réactions en Solution, *by G. Charlot and R. Gauguin. Pp.* 328, *with* 242 *figures. Masson et Cie, Paris.* 2200 *francs net.*

Principles of Phase Equilibria, *by F. E. W. Wetmore and D. J. Le Roy. Pp.* 200, *with various line diagrams. McGraw-Hill Publishing Company Limited, London.* 1951. 30*s. net.*

Safety in the Chemical Laboratory, *by H. A. J. Pieters in collaboration with J. W. Creyghton. Pp.* 258, *with various line diagrams. Butterworth's Scientific Publications Limited, London.* 1951. 15*s. net.*

The Solubility of Nonelectrolytes, *by Joel H. Hildebrand and Robert L. Scott. Pp.* 488, *with numerous line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 3rd edition,* 1950. 80*s. net.*

GENERAL SCIENCE

British Journal for the Philosophy of Science, *February* 1951. *Vol. I, No.* 4. *Pp.* 257–340. *Thomas Nelson and Sons Limited, Edinburgh.* 1951. 7*s.* 6*d. net.*

A Century of Science, *edited by Herbert Dingle. Pp.* 338, *with half-tone and line illustrations. Hutchinson's Scientific and Technical Publications, London.* 1951. 15*s. net.*

INDUSTRY

Eyes in Industry, *by D. A. Campbell, W. J. B. Riddell, and A. S. MacNalty. Pp.* 234, *with half-tone and coloured illustrations. Longmans, Green and Company Limited, London.* 1951. 30*s. net.*

Industrial Research in Switzerland, *by Ronald S. Edwards in collaboration with Charles La Roche. Pp.* 111. *Sir Isaac Pitman and Sons Limited, London.* 1951. 21*s. net.*

PHOTOGRAPHY

Progress in Photography 1940–1950, *Editor-in-chief D. A. Spencer. Pp.* 460, *with many half-tone illustrations and line diagrams. Focal Press Limited, London.* 1951. 42*s. net.*

PHYSICS

Conductive Analysis at Radio-Frequency, *by G. G. Blake. Pp.* 109, *with various line diagrams. Chapman and Hall Limited, London.* 1951. 15*s. net.*

Essay in Physics, *by Viscount Samuel. Pp.* 154. *Basil Blackwell, Oxford.* 1951. 7*s.* 6*d. net.*

An Introduction to Servo Mechanisms, *by A. Porter. Pp.* 134, *with numerous line diagrams. Methuen and Company Limited, London.* 1950. 7*s.* 6*d. net.*

Metallurgical Thermochemistry, *by O. Kubaschewski and E. Ll. Evans. Pp.* 368, *with numerous line diagrams. Butterworth-Springer Limited, London.* 1951. 35*s. net.*

The Microphysical World, *by William Wilson. Pp.* 216, *with numerous line diagrams. Methuen and Company Limited, London.* 1951. 5*s. net.*

The Principles of Cloud-Chamber Technique, *by J. G. Wilson. Pp.* 131, *with numerous line diagrams. Cambridge University Press, London.* 1951. 15*s. net.*

A Short History of Radio-Activity, *by T. W. Chalmers. Pp.* 78, *with numerous line diagrams. Published at the offices of* The Engineer, *London.* 1951. 8*s.* 6*d., post free.*

Source Book on Atomic Energy, *by Samuel Glasstone. Pp.* 546, *with half-tone and line diagrams. Macmillan and Company Limited, London.* 1951. 24*s. net.*

TECHNOLOGY

Aspects of the Constitution of Mineral Oils, *by K. Van Nes and H. A. Van Westen. Pp.* 484, *with numerous line diagrams. Elsevier Publishing Company Limited, Amsterdam; Cleaver-Hume Press Limited, London.* 1951. 70*s. net.*

Glass: a Handbook for Students and Technicians, *edited by J. Home Dickson. Pp.* 300, *with numerous half-tone and line illustrations. Hutchinson's Scientific and Technical Publications, London.* 1951. 25*s. net.*

Zinc and Spelter: Notes on the Early History of Zinc, *by J. M. Dawkins. Pp.* 35, *with half-tone and line illustrations. Zinc Development Association, Oxford.* 1950. *No charge.*

ZOOLOGY

Animal Evolution, *by G. S. Carter. Pp.* 368, *with half-tone and line illustrations. Sidgwick and Jackson Limited, London.* 1951. 30*s. net.*

Zoogeography of the Land and Inland Waters, *by L. F. de Beaufort. Pp.* 208, *with several line diagrams. Sidgwick and Jackson Limited, London.* 1951. 30*s. net.*

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Has held the position of Astronomer Royal since the year 1933. He was born in London in 1890 and was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge. From 1923 to 1933 he held the post of His Majesty's Astronomer at the Cape of Good Hope. He was knighted in 1943. He has received the Royal Medal of the Royal Society, the Gold Medal of the Royal Astronomical Society, the Janssen Medal of the Astronomical Society of France, the Bruce Gold Medal of the Astronomical Society of the Pacific, and the Gold Medal of the British Horological Institute. He is a past president of the Royal Astronomical Society, of the British Astronomical Association, of the Institute of Navigation, and of the International Astronomical Union. He is president of the British Horological Institute and of the Society for Visiting Scientists. He is a foreign member of many national academies and an honorary member of many Dominion and foreign astronomical societies.

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Born in Vienna. Trained at the universities of Vienna, Reading, Cambridge, and London. Began investigations on the production of antibiotics in the soil and the control of plant diseases by microbial antagonism in 1945, when on the staff of the Experimental and Research Station, Cheshunt. This work was carried out for the Agricultural Research Council. Transferred in 1949 to the Botany Department of Imperial College, London, where she is at present continuing the above investigations.

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Born in Edinburgh in 1903. Educated at Marlborough College and at Trinity College, Cambridge. Assistant to the professor of botany (H. H. Dixon), Trinity College, Dublin, 1924–30. Since then he has held a lectureship in Manchester University and two chairs of botany at Nottingham and now at King's College, London. His research interests lie in plant physiology, and in particular in the study of the interrelationships of respiration and secretory or accumulation mechanisms.

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Born 1902; educated at King's Norton School and the Imperial College of Science and Technology. Chief Technical Officer, Royal Airship Works, 1931; Principal Scientific Officer, Aerodynamics Dept., Royal Aircraft Establishment, 1935–6; Head of Air Defence Dept., R.A.E., 1936–8; Chief Technical Officer, Air Registration Board, 1938–9; Superintendent of scientific research, R.A.E., 1939–40; deputy director of scientific research, Ministry of Aircraft Production, 1940–3; director of special projects, Ministry of Aircraft Production, 1943–4; chairman and managing director of Power Jets (Research and Development) Ltd., 1944–6; director of the National Gas Turbine Establishment, 1946–8. A governor of the College of Aeronautics; member of the Aeronautical Research Council, 1944–8. Past president of the Royal Aeronautical Society. Chief scientist, Ministry of Fuel and Power, since 1948. Publications: numerous papers on theory of structures, wing flutter, gas turbines, civil aviation, and airships.

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M.A., F.R.S.E., F.R.S.

Born 1894. Educated Friars' School, Bangor, University College of North Wales (1912–14), and Trinity Hall, Cambridge (1919–24). Since 1924 at Armstrong College (now King's College), Newcastle upon Tyne, first as lecturer in botany, then as reader in plant physiology, and now as professor of botany. Publications: *Textbook on Plant Physiology;* papers on carbohydrate catabolism with alcohol accumulation (zymasis) and the bearing of zymasis on certain physiological diseases of apples, and, more recently, papers on crassulacean acid metabolism.

ENDEAVOUR

The British quarterly scientific review ENDEAVOUR was first published in January 1942. Its purpose was to enable men of science, and particularly British men of science, to speak to the world in an hour when not only nations but the internationalism of science suffered the dangers of warfare. For the better fulfilment of this purpose ENDEAVOUR was from the first published in four separate editions—English, French, Spanish, and German. An Italian edition has been published since January 1948. Today the situation is happily different, but there can be no lasting peace without full and sincere co-operation between nations in every realm of human enterprise. In the scientific field ENDEAVOUR can thus play as useful a part in peace as it did in war, and for this reason the decision has been taken to make its publication permanent.

ENDEAVOUR is distributed without charge to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

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